Fishery Data Series No. 97-30

Stock Status of Arctic Grayling in the Chena River and Badger Slough During 1996

by

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and

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November 1997

Alaska Department of Fish and Game Division of Sport Fish

Symbols and Abbreviations

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
metric ton	mt
milliliter	ml
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
ounce	oz
pound	lb
quart	qt
yard	yd

Spell out acre and ton.

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
hour (spell out for 24-hour clock)	h
minute	min
second	s

Spell out year, month, and week.

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

All commonly accepted abbreviations.	e.g., Mr., Mrs., a.m., p.m., etc.
All commonly accepted professional titles.	e.g., Dr., Ph.D., R.N., etc.
and	&
at	@
Compass directions:	
east	E
north	N
south	S
west	W
Copyright	©
Corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
et alii (and other people)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.,
id est (that is)	i.e.,
latitude or longitude	lat. or long.
monetary symbols (U.S.)	\$, ¢
months (tables and figures): first three letters	Jan,...,Dec
number (before a number)	# (e.g., #10)
pounds (after a number)	# (e.g., 10#)
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S. state and District of Columbia abbreviations	use two-letter abbreviations (e.g., AK, DC)

Mathematics, statistics, fisheries

alternate hypothesis	H_A
base of natural logarithm	e
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	F, t, χ^2, etc.
confidence interval	C.I.
correlation coefficient	R (multiple)
correlation coefficient	r (simple)
covariance	cov
degree (angular or temperature)	°
degrees of freedom	df
divided by	÷ or / (in equations)
equals	=
expected value	E
fork length	FL
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	log_2, etc.
mideye-to-fork	MEF
minute (angular)	'
multiplied by	x
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
standard length	SL
total length	TL
variance	Var

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by

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November 1997

Development and publication of this manuscript were partially financed by the Federal Aid in Sport Fish Restoration Act (16 U.S.C. 777-777K) under Project F-10-12, Job No's. 3-2(a) and 3-2(b).

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This document should be cited as:
Ridder, W. P. and D. F. Fleming 1997. Stock status of Arctic grayling in the Chena River and Badger Slough during 1996. Alaska Department of Fish and Game, Fishery Data Series No. 97-30, Anchorage.

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ABSTRACT

Stock status of Arctic grayling *Thymallus arcticus* in the lower 152 km of the Chena River was described by population abundance, age composition, size composition, recruitment, and survival rate estimates during 1996. In July of 1996, estimated abundance of Arctic grayling in the Chena River was 42,850 fish (SE = 4,163) ≥ 150 mm FL. Age-3 Arctic grayling were strongly represented in the Chena River, representing 38 % of fish ≥ 150 mm FL. Stock-size Arctic grayling (150-269 mm FL) represented 66 % of fish ≥ 150 mm FL. Annual recruitment between 1995 and 1996 was 15,605 Arctic grayling (SE = 1,851) and annual survival during this period was 78.2 % (SE = 6.5).

Estimated abundance of 1992 brood year (age-4) hatchery-reared Arctic grayling, released in 1993, was 815 fish (SE = 125). Survival of age-4 hatchery-reared Arctic grayling from July of 1995 to July of 1996 was 40.4 % (SE = 1.7). Estimated abundance of 1993 brood year (age-3) hatchery-reared Arctic grayling, released in 1994, was 573 fish (SE = 102). Survival of age-3 hatchery-reared Arctic grayling from July of 1995 to July of 1996 was 24.6 % (SE = 1.4). From 1992 through 1994, a total of 126,371 age-1 and 23,199 age-0 Arctic grayling have been released into the Chena River. Estimated abundance of all releases of Arctic grayling in 1996 was 1,388 fish (SE = 161). Low initial post-release survival (~60% during the first month) and low overwinter survival (~8% per year) were the primary causes of failure of the releases.

Stock status of Arctic grayling within 5.7 km of Badger Slough during May 1996 was described by abundance, age composition, and size composition. Additionally, the relative contribution was estimated for fish present in Badger Slough in May that were present in the Chena River in July. In May 1996, the estimated abundance of Arctic grayling in Badger Slough was 9,496 (SE = 1,801) ≥ 220 mm FL. Age-5 (28%) and age-6 (23%) fish predominated the age composition in Badger Slough during the spring spawning period. Arctic grayling between 250 and 289 mm FL comprised an estimated 48% of fish present. Relative contribution rate estimates indicated that 6% of Arctic grayling ≥ 220 mm FL and 4% of fish ≥ 270 mm FL present in July along the 152 km assessed portion of the Chena River were also part of the assessed stock in Badger Slough during May.

Key words: Arctic grayling, *Thymallus arcticus*, electrofishing, population abundance, age composition, size composition, Relative Stock Density, recruitment, survival rate, rehabilitation, Chena River, Badger Slough, contribution.

INTRODUCTION

BACKGROUND

The Chena River is a clear water tributary to the Tanana River originating in the Tanana Uplands 144 km east of Fairbanks and flowing approximately 252 km from its uppermost reach in the East Fork to its confluence with the Tanana River at Fairbanks. The river drains a watershed of 5,130 km^2 and includes five major tributaries: North Fork, West Fork, South Fork, East Fork, and the Little Chena River (Figure 1). Collectively, these major tributaries and the mainstem are over 470 km in length. Urban development along the river is extensive along the lower 40 km of the river while road accessibility extends along a majority of the lower 168 km.

The Chena River provides habitat for 14 fish species: Arctic grayling *Thymallus arcticus*, chinook salmon *Oncorhynchus tshawytscha*, chum salmon *O. keta*, round whitefish *Prosopium cylindraceum*, slimy sculpin *Cottus cognatus*, burbot *Lota lota*, longnose sucker *Catostomus catostomus*, Arctic lamprey *Lampetra japonica*, northern pike *Esox lucius*, sheefish *Stenodus leucichthys*, humpback whitefish *Coregonus pidschian*, broad whitefish *C. nasus*, least cisco *C. sardinella* and lake chub *Couesius plumbeus*. The latter six species are more likely found in the lower half of the river while the former eight species may be found throughout the river.

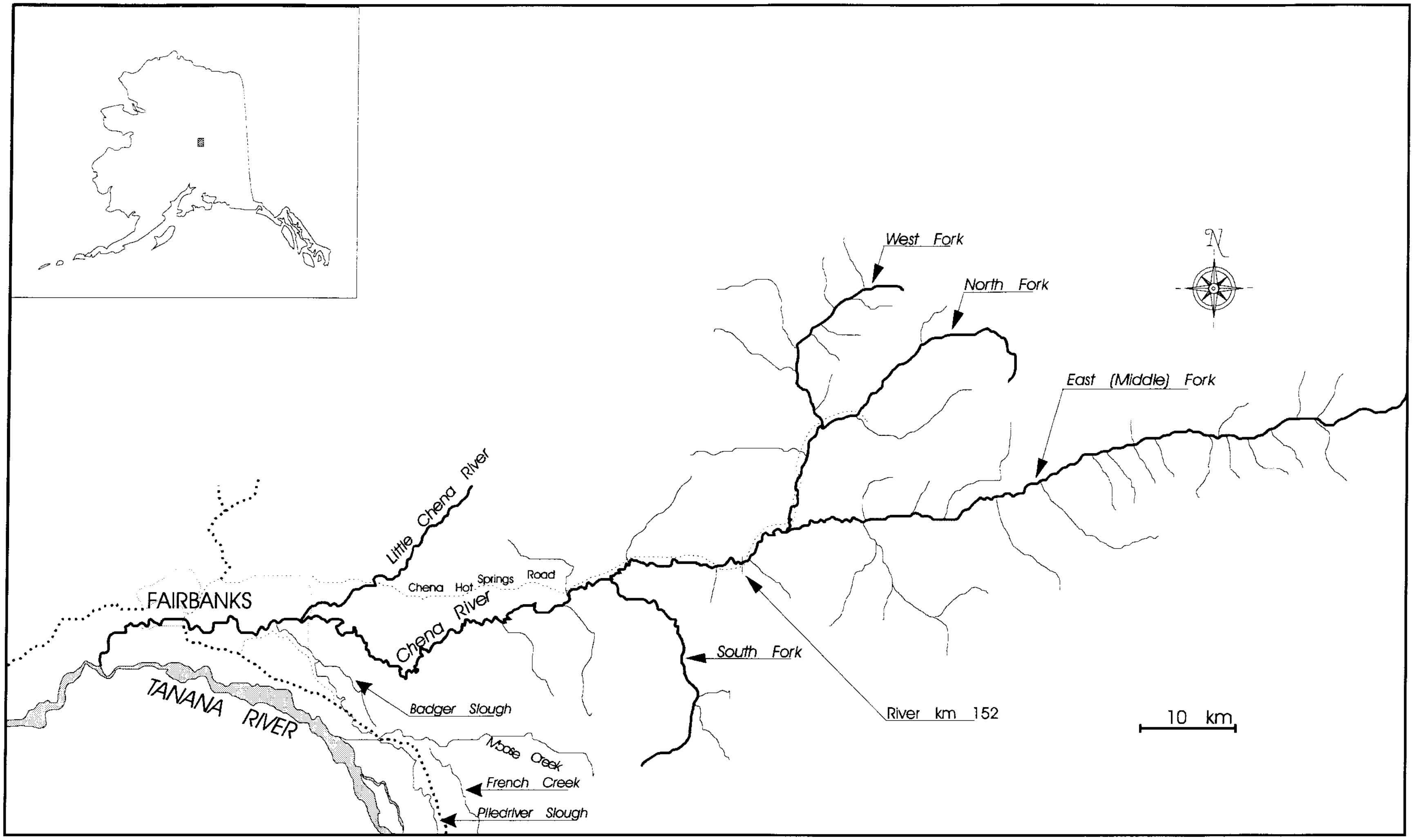


Figure 1.- The Chena River drainage.

Recreational fisheries are conducted on nine of the 14 species (in parenthesis is total catch in 1995 from Howe et al. 1996): Arctic grayling (39,270), the two salmons (2,692), northern pike (1,890), burbot (1,045), and whitefish (445). By regulation, salmon fishing is closed above river kilometer 72.

Due to its proximity to Fairbanks and road accessibility, the Chena River supports the largest Arctic grayling fishery in North America. However, the status and character of the fishery has changed dramatically since 1985. From 1977 through 1984, annual harvests averaged 30,000 Arctic grayling and annual angling effort for all species averaged 34,000 angler days (Mills 1979-1985, Table 1, Figure 2). Since 1985, harvests have declined dramatically to an average of 4,400 Arctic grayling while effort has decreased to 27,900 angler days (Mills 1986-1994, Howe et al. 1995-1996, Table 1, Figure 2). The fishery has been closed to harvest since 1992, however illegally taken fish have been reported in the statewide harvest survey (Table 1). Concomitant with the rapid decline in harvest was a decline in Arctic grayling population abundance. Stock assessment projects during 1986 (Clark and Ridder 1987b) and 1987 (Clark and Ridder 1988) documented a decline in population abundance of 49% between these two years. These trends in the fishery and population prompted fishery managers to process emergency regulations for the 1987 season to reduce harvest. These emergency regulations (1 through 3) were adopted and amended (4 and 5) by the Alaska Board of Fisheries and were:

1. catch-and-release fishing from 1 April to the first Saturday in June;
2. a 12 inch (305 mm) minimum total length limit from the first Saturday in June until 31 March;
3. restriction of terminal gear to unbaited artificial lures only throughout the Chena River, and bait fishing allowed downstream of the Moose Creek Dam with hooks having a gap larger than 0.75 inch (19 mm);
4. catch-and-release fishing year around from river kilometer 140.8 downstream to river kilometer 123.2; and,
5. reduce the possession limit from 10 to 5 fish (Tanana River drainage-wide regulation).

These regulations were the first changes in Arctic grayling management since 1975, when the daily bag limit was decreased from 10 to 5 fish.

By 1990, annual evaluation of the effects of these new regulations showed little effect on the population and fishery trends which prompted the Board of Fisheries to implement a daily bag limit of two fish drainage-wide and single hook regulations upstream of the Moose Creek Dam. On 1 July 1991, fishery managers invoked Emergency Order authority to reduce the daily bag limit to 0 fish in the entire Chena River drainage. This Emergency Order remained in effect through 1994. In 1994, the Board of Fisheries passed a regulation to keep the daily bag limit at 0 fish through 1997. Since 1991 and the imposition of catch and release regulations, the trend in the population and the fishery has been upward. Abundance of Arctic grayling has increased from 26,800 fish in 1991 to 45,000 fish in 1995 (Clark 1993, Clark 1996) while angling effort has increased from 12,654 angler days in 1992 to 37,479 angler days in 1995 (Table 1).

Along with the imposition of catch and release regulations in 1991, fishery managers began a rehabilitation program for Arctic grayling in the Chena River. The rehabilitation program had two main parts: regulation changes to ensure adequate protection of the stock, and a program of

Table 1.-Summary of total angling effort and Arctic grayling harvest on the Chena River, 1977-1995 (taken from Mills 1979-1994 and Howe et al. 1995-1996).

	Lower Chena River[a]		Upper Chena River[b]		Entire Chena River	
Year	Angler-days	Harvest	Angler-days	Harvest	Angler-days	Harvest
1977[c]	---	---	---	---	30,003	21,723
1978[c]	---	---	---	---	38,341	33,330
1979	9,430	11,290	8,016	11,664	17,446	22,954
1980	13,850	18,520	10,734	16,588	24,584	35,108
1981	11,763	10,814	10,740	13,735	22,503	24,549
1982	18,818	11,117	15,166	12,907	33,984	24,024
1983	17,568	7,894	16,725	10,835	34,293	18,729
1984	20,556	13,850	11,741	12,630	32,297	26,480
1985	11,169	2,923	8,568	3,317	19,737	6,240
1986	18,669	4,167	10,688	3,695	29,357	7,862
1987[d]	12,605	1,230	10,667	1,451	23,272	2,681
1988[d,e]	16,244	2,686	9,677	1,896	25,921	4,582
1989[d,e]	20,317	7,194	10,014	5,441	30,331	12,635
1990[d,e,f]	18,957	3,494	6,949	945	25,906	4,439
1991[d,e,f,g]	12,547	2,997	8,591	722	21,138	3,719
1992[h]	7,671	0	4,983	0	12,654	0
1993[h]	15,631	0	6,018	0	21,649	0
1994[h]	19,280	33	7,912	82	27,192	115
1995[h]	24,160	0	13,319	212	37,479	212
Averages[i]	15,837	5,777	10,030	5,654	25,867	13,346

a Lower Chena River is from the mouth upstream to 40 km Chena Hot Springs Road (Mills 1988). For 1991 through 1995 the Lower Chena River included Badger Slough. Angling effort is for all species of fish.

b Upper Chena River is the Chena River and tributaries accessed from the Chena Hot Springs Road beyond 40 km on the road (Mills 1988). Angling effort is for all species of fish.

c Angler-days and harvest are computed for the Chena River and Badger Slough.

d Special regulations were in effect during 1987 through 1991. These regulations were: catch-and-release fishing from 1 April until the first Saturday in June; a 305 mm (12 inch) minimum length limit; and, a restriction of terminal gear to unbaited artificial lures.

e In addition to the special regulations, a catch-and-release area was created on the Upper Chena River (river km 140.8 to 123.2).

f The daily bag and possession limits were reduced from five fish to two fish in 1990.

g During 1991, the Chena River and its tributaries were closed to possession of Arctic grayling from 1 July through 31 December.

h During 1992 through 1995, the Chena River and its tributaries were closed to possession of Arctic grayling from 1 January through 31 December.

i Averages are for 1979 through 1995 only.

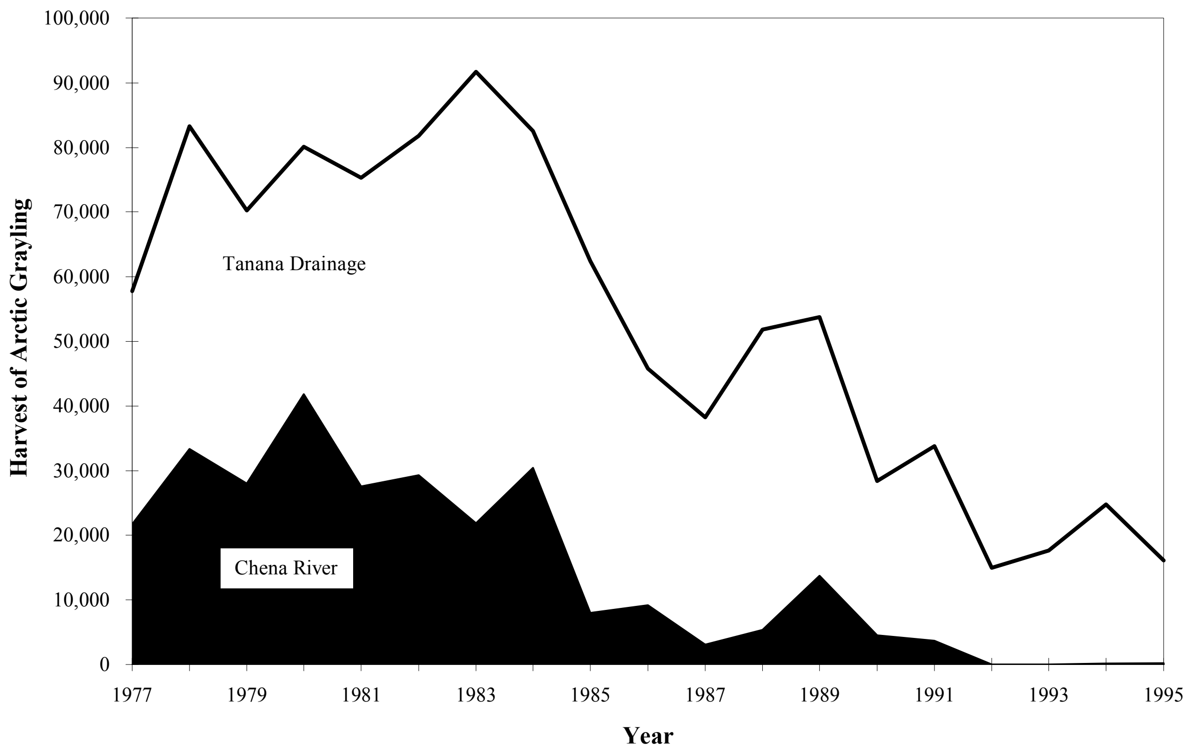


Figure 2.-Annual harvests of Arctic grayling in the Chena River and in the entire Tanana River drainage, 1977-1995 (taken from Mills 19879-1994 and Howe et al. 1995-1996).

supplementation of natural production with releases of hatchery and pond-reared Arctic grayling. Beginning in spring of 1992, the first lot of fertilized eggs were taken from the Chena River stock for use in supplementing natural production. During 1993 a second lot of fertilized eggs were taken and 64,936 97-g fish (1992 brood year) were stocked into the Chena River from Clear Hatchery. During 1994, 61,435 94-g fish (1993 brood year) were stocked. Stock assessment of Arctic grayling in 1996 focused on separation of hatchery fish from wild fish for individual estimates of abundance, size composition, and annual survival.

OBJECTIVES FOR STOCK ASSESSMENT

In order to accurately and precisely describe the stock status of Arctic grayling in the Chena River, the following objectives were addressed in 1996:

1. to estimate the abundance of Arctic grayling ≥ 150 mm FL in the lower 152 km of the Chena River;
2. to estimate the proportion of Arctic grayling (≥ 150 mm FL) in each of four groups (wild fish, age 3 hatchery releases, age 4 hatchery releases, and age 4 pond-reared releases) in the lower 152 km of the Chena River;
3. to estimate the age composition of wild Arctic grayling in the lower 152 km of the Chena River; and,
4. to estimate the size composition of Arctic grayling (wild fish, age 3 hatchery releases, age 4 hatchery releases, and age 4 pond-reared releases) in the lower 152 km of the Chena River.

In addition to these primary objectives, recruitment of new fish to the stock, the annual survival rate of the stock, and survival of age 3 and age 4 hatchery releases were estimated. A task of the project is to evaluate the present stock assessment program in the Chena River in regards to fiscal and biological efficiency, and this evaluation is ongoing. Objectives and results of research performed in Badger Slough are summarized in Appendix A.

METHODS

SAMPLING GEAR AND TECHNIQUES

During 1996, all sampling was performed with pulsed-DC (direct current) electrofishing systems mounted on 6.1-m-long river boats as previously described by Lorenz (1984). Input voltage (240 VAC) was provided by a 3,500 or 3,800 W single-phase gas powered generator. A variable voltage pulsator (Coffelt Manufacturing Model VVP-15) was used to generate output current. Anodes were constructed of 16.0 mm diameter and 1.5 m long twisted steel cable. Four anodes were connected to the front of a 3-m-long "T-boom" attached to a platform at the bow of the river boat. The aluminum hull of the river boat was used as the cathode. Output voltages during sampling varied from 200 to 300 VDC. Amperage varied from 2.5 to 4.0 A. Duty cycle and pulse rate were held constant at 50% and 60 Hz, respectively. These operating characteristics were presumed to minimally affect Arctic grayling survival during mark-recapture experiments.

Sampling was conducted along the banks of the Chena River, which was divided into upper and lower sections. For each event, one pass was made through each study section. In the Lower Chena section, two electrofishing boats were each directed downstream along one bank, capturing all Arctic grayling seen, when possible. In the Upper Chena section, one electrofishing boat was directed downstream selectively fishing one bank or the other. Due to the section's narrow width and frequent meanders, preferred Arctic grayling habitat is seldom along both banks. Captured Arctic grayling were held in an aerated holding tub to reduce capture related stress. The two river sections were sampled no more than once per day to prevent changes in capture probabilities of marked fish (Cross and Stott 1975). Each Arctic grayling was measured to the nearest 1 mm FL. During the second event of the mark-recapture experiments, a scale sample was taken from an area approximately six scale rows above the lateral line just posterior to the insertion of the dorsal fin of each wild Arctic grayling. In the Lower Chena section, Arctic grayling ≥ 150 mm FL were marked with a partial right pectoral clip in the first event and a partial upper caudal clip for the second event. In the Upper Chena section, Arctic grayling ≥ 150 mm FL were marked with a partial left pectoral clip in the first event and a partial lower caudal clip for the second event. Since fish regenerate clipped fins over the course of a year, fish marked in prior years received the same treatment as all fish captured in 1996. All enhancement fish (hatchery and pond-reared releases) were marked with a complete fin clip (complete left or right ventral for hatchery and adipose for pond-reared releases) prior to release. If any captured Arctic grayling exhibited signs of injury or imminent mortality, they were immediately dispatched.

ESTIMATION OF ABUNDANCE

The abundance of Arctic grayling ≤ 150 mm FL was estimated by mark-recapture techniques in the lower 152 km of the mainstem` Chena River (Figure 2). Two sections of the Chena River were delineated for separate estimation experiments. Delineation of the Chena River was necessary because of differences in capture probability of Arctic grayling in different sections of river (Figure 3). Based on differences in capture probability from downstream to upstream areas of the Chena River, the lower 152 km of the Chena River is divided into Lower and Upper sections for estimating abundance and age composition. Downstream from the Moose Creek Dam complex to river kilometer 8 of the Chena River was designated the Lower Chena section (64 km long; Figure 3). Upstream from the dam to the first bridge on the Chena Hot Springs Road (river kilometer 62.4) was designated the Upper Chena section (80 km long; Figure 3). Population abundance estimates pertain only to these two sections of the Chena River, excluding Badger Slough, the Little Chena River, and the South Fork of the Chena River.

Abundance of Arctic grayling ≥ 150 mm FL was estimated with the modified Petersen estimator of Bailey (1951, 1952). Two electrofishing boats were used to mark Arctic grayling along both banks of the Lower Chena section (64 km long) and one electrofishing boat was used in the Upper Chena section (80 km long). Marking of fish in each section required four days, sampling four areas within a section. After a hiatus of seven days the three electrofishing boats were used in the same way to capture marked and unmarked Arctic grayling. The Upper and Lower Chena experiments were conducted concurrently during the first two weeks of July in 1996.

The assumptions necessary for accurate estimation of abundance in a closed population are (from Seber 1982):

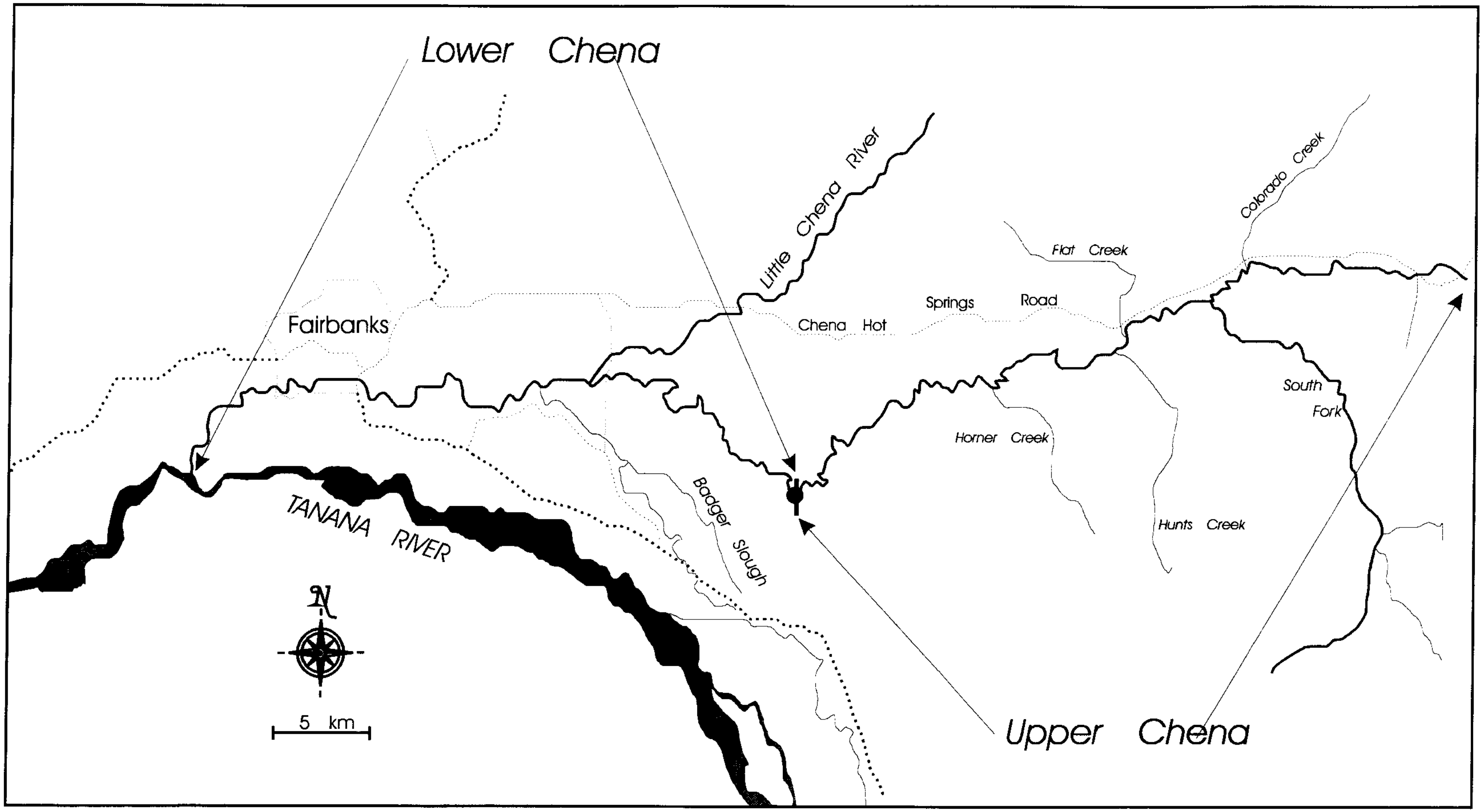


Figure 3.- Stock assessment sections in 1996 along the lower 152 km of the Chena River drainage.

1. the population is closed (no change in the number of Arctic grayling in the population during the estimation experiment);
2. all Arctic grayling have the same probability of capture in the first sample or in the second sample, or marked and unmarked Arctic grayling mix completely between the first and second samples;
3. marking of Arctic grayling does not affect their probability of capture in the second sample;
4. Arctic grayling do not lose their mark between sampling events; and,
5. all marked Arctic grayling are reported when recovered in the second sample.

Testing of Assumptions

Assumption 1 was implicitly assumed because of the large size of the sections (64 and 80 km) and short duration of the experiments (two weeks). A large section of river reduced the probability of fish leaving the section between sampling events. The short duration reduced the likelihood that mortality or recruitment due to growth would occur between sampling events. Assumptions 4 and 5 were assumed to be valid because of double marking of tagged Arctic grayling and rigorous examination of all captured Arctic grayling.

Assumptions 2 and 3 were tested directly in three ways. First, changes in capture probability may have occurred within a section of river. These potential changes were investigated by dividing each river section into four areas, each area encompassing the distance traveled during a single day of electrofishing. To determine if capture probability did change between areas, the recapture-to-catch ratios of each area were compared using a chi-squared contingency table. The four rows of the table were the different areas and the two columns of the table were the number of recaptures in the area and the number of unmarked fish examined during the second event in the same area. If the recapture-to-catch ratios were significantly different ($\alpha = 0.05$), the data were stratified into areas and separate abundance estimates calculated for each area.

Secondly, capture probability may differ by size of fish. Electrofishing is notorious for selecting for the largest fish in a population (Reynolds 1983), so that larger fish have a higher capture probability than smaller fish. Two Kolmogorov-Smirnov (KS) statistical tests were used to determine if capture probability differs by size of fish. The first KS test compared the length frequency distribution of recaptured Arctic grayling with those captured during the marking event. The second KS test compared the length frequency distribution of Arctic grayling captured during the marking event with those captured in the recapture event (see Bernard and Hansen 1992 for a description of tests). The first KS test was used to determine if capture probability varied by size of fish. If significantly different, the size at stratification was determined by performing a series of chi-squared tests at differing sizes (using two size strata). The size at stratification that produced the largest chi-squared value (the greatest difference in capture probability) was used to stratify the data for separate abundance estimation. The second KS test was used to determine if age and size data needed to be corrected for changes in capture probability (see Estimation of Age and Size Composition below).

In the Upper Chena section, a loss of length data occurred that compromised the testing of assumptions. On the first day of the mark event in the Upper Chena section, the lone electrofishing boat was sunk early on the seventh electrofishing run with the loss of all length data. Fortunately, in addition to collecting data on individual fish, a tally sheet is kept that tabulates number of fish caught, killed, and released in each electrofishing run along with cumulative totals. Immediately after noting the loss of the data, the crew recollected and noted the totals from the tally sheet. With the loss of this data (438 fish caught, 436 fish marked and released), the above KS tests were run on a subset of data representing only the fish from the remaining electrofishing runs (runs eight through 30). The assumption was made that the total fish caught in the first event were similar in composition to the reduced subset. In the second event, fish from runs eight through 30 were compared to fish from all runs and were not found to be significantly different. ($D = 0.04$, $p = 0.49$).

Calculation of Abundance

After mark-recapture data were considered for stratification into areas and/or size with equal capture probabilities, estimated abundance was calculated from numbers of Arctic grayling marked, examined for marks, and recaptured (Bailey 1951; Seber 1982):

$$\hat{N}_i = \frac{n_1(n_2+1)}{m_2+1} \tag{1}$$

where:

n_1 = the number of Arctic grayling marked and released alive during the first sample in stratum *i*;

n_2 = the number of Arctic grayling examined for marks during the second sample in stratum *i*;

m_2 = the number of Arctic grayling recaptured during the second sample in stratum *i*; and,

$\hat{N}_i$ = estimated abundance of Arctic grayling during the first sample in stratum *i*.

Variance was estimated by (Seber 1982):

$$\hat{V}\left[\hat{N}_i\right] = \frac{n_1^2(n_2+1)(n_2-m_2)}{(m_2+1)^2(m_2+2)} \tag{2}$$

Bailey's (1951, 1952) modification was used instead of the more familiar modification by Chapman (1951) because of the sampling design used on each river section. Seber (1982) found that if the assumption of a random sample for the second sample was false and a systematic sample was taken (for example, a systematic sample of both banks of the Chena River), then the binomial model of Bailey (1951, 1952) is most appropriate. The binomial model will hold in this situation when:

1. there is uniform mixing of marked and unmarked fish; and,
2. all fish, whether marked or unmarked, have the same probability of capture.

The sample design used in each river section does not allow for thorough mixing of fish marked at the uppermost reaches with those marked in the downstream reaches, although local mixing of marked and unmarked fish probably occurs.

Estimated abundance and variance of wild and hatchery fish in the lower 152 km of the Chena River was calculated as the sum of all strata (either areas, sizes, or both) from the Lower and Upper Chena sections:

$$\hat{N} = \sum_{i=1}^{s} \hat{N}_i \text{ , and} \tag{3}$$

$$\hat{V}\left[\hat{N}\right] = \sum_{i=1}^{s} \hat{V}\left[\hat{N}_i\right]. \tag{4}$$

where: s = the number of strata needed to alleviate bias due to changes in capture probability.

In 1996 there were three strata (s = 3): one strata representing the Lower Chena section and two size strata representing the Upper Chena section. Abundance of age-3 and age-4 hatchery-reared fish was estimated by apportioning the abundance of all fish by the proportion of age-3 and age-4 hatchery-reared fish in catches. First, the proportion of age-3 or age-4 hatchery-reared fish in catches of all fish was estimated:

$$\hat{r}_{AGEx} = \frac{n_{AGEx}}{n_{ALL}} \tag{5}$$

where: $\hat{r}_{AGEx} =$ the proportion of age *x* hatchery-reared fish in the catch; n_{AGEx} = the number of age *x* hatchery-reared fish in the catch (n_2 from equation 1); and, n_{ALL} = the total number of fish in the catch.

Variance of this proportion was estimated as the variance of a binomial. The abundance of age-3 or age-4 hatchery-reared fish was then estimated from the mark-recapture estimate of abundance and the estimated proportion:

$$\hat{N}_{AGEx} = \hat{r}_{AGEx}\hat{N}_{ALL} \tag{6}$$

where: $\hat{N}_{AGEx} =$ the abundance of age *x* hatchery-reared fish; and, $\hat{N}_{ALL} =$ the abundance of all fish.

Variance of equation six was estimated with the formula for the variance of the product of two independent variables (Goodman 1960):

$$\hat{V}\left[\hat{N}_{AGEx}\right] = \hat{r}^2_{AGEx}\hat{V}\left[\hat{N}_{ALL}\right] + \hat{N}^2_{ALL}\hat{V}\left[\hat{r}_{AGEx}\right] - \hat{V}\left[\hat{N}_{ALL}\right]\hat{V}\left[\hat{r}_{AGEx}\right] \tag{7}$$

Estimates of age-3 or age-4 hatchery-reared fish were then summed by river section as in equations three and four.

ESTIMATION OF AGE AND SIZE COMPOSITION

Age-length samples of wild Arctic grayling were collected in conjunction with abundance estimation experiments. Age composition was described with proportions of the stock contained in each age class from two through 12 years (third through thirteenth summers, respectively). Size composition of Arctic grayling in each of the river sections was described with the incremental Relative Stock Density (RSD) indices of Gabelhouse (1984). The RSD categories are: "stock" (150 to 269 mm FL); "quality" (270 to 339 mm FL); "preferred" (340 to 449 mm

FL); "memorable" (450 to 559 mm FL); and, "trophy" (greater than 559 mm FL). Incremental size composition was also estimated for each 10 mm increment of fork length from 150 mm to 450 mm. Incremental size composition was also used to describe the sizes of hatchery-reared fish sampled in the Chena River.

Differences in capture probability may also bias estimates of age and size compositions. If significant changes in capture probability were detected, age and size data were adjusted for these differences so that the age and size composition of Arctic grayling in the lower 152 km of the Chena River could be estimated. First, the proportions of fish by age class or size category were estimated for each stratum used in estimation of abundance:

$$\hat{p}_{ik} = \frac{n_{ik}}{n_i} \tag{8}$$

where: $\hat{p}_{ik}$ = the proportion of age or size category *k* fish sampled in stratum *i*; n_{ik} = the number of age or size category *k* fish sampled in stratum *i*; and, n_i = the number of fish sampled in stratum *i*.

Variance of this proportion was estimated as the variance of a binomial. The abundance of each age class or size category was then estimated from the proportions and abundance in each stratum:

$$\hat{N}_{ik} = \hat{p}_{ik}\hat{N}_i \tag{9}$$

where: $\hat{N}_{ik}$ = the abundance of age or size category *k* fish in stratum *i*.

Variance of each abundance at age or size was estimated with the formula for the variance of the product of two independent variables (as in equation 7). After calculating abundances at age or size in each stratum, the overall proportions were estimated by:

$$\hat{\bar{p}}_k = \sum_{i=1}^{s} \frac{\hat{N}_i}{\hat{N}}\hat{p}_{ik} \tag{10}$$

where: $\hat{N}_i / \hat{N}$ = weight for stratum i; $\hat{\bar{p}}_k$ = the average weighted proportion of Arctic grayling in the lower 152 km of the Chena River that were age or size *k*; $\hat{N}_i$ = the abundance of Arctic grayling in stratum i; $\hat{N}$ = summed abundance of all strata (from equation 3); and, $\hat{p}_{ik}$ = the proportion of Arctic grayling in stratum *i* that were age or size *k*.

Variance of the proportions were approximated with the Delta method (see Seber 1982):

$$\hat{V}\left[\hat{\bar{p}}_k\right] \approx \sum_{i=1}^{s} \frac{\left(\hat{p}_{ik} - \hat{\bar{p}}_k\right)^2 \hat{V}\left[\hat{N}_i\right]}{\hat{N}^2} + \sum_{i=1}^{s}\left(\frac{\hat{N}_i}{\hat{N}}\right)^2 \hat{V}\left[\hat{p}_{ik}\right] \tag{11}$$

These average weighted proportions and variances by age and size were used as estimates of age and size compositions in the lower 152 km of the Chena River.

ESTIMATION OF PROPORTION OF HATCHERY-REARED FISH

The proportion of age-3 and age-4 hatchery-reared fish in the lower 152 km of the Chena River was estimated as the quotient of the abundance of age-3 or age-4 hatchery-reared fish and total abundance (wild plus all enhancement cohorts):

$$\hat{p}_{AGEx} = \frac{\hat{N}_{AGEx}}{\hat{N}_{AGE3} + \hat{N}_{WILD} + \hat{N}_{AGE4}} = \frac{\hat{N}_{AGEx}}{\hat{N}_{ALL}} \tag{12}$$

where: $\hat{p}_{AGEx}$ = proportion of the population that was from age *x* hatchery-reared releases in the lower 152 km of the Chena River; and, $\hat{N}_x$ = abundance of age-3 (AGE3) hatchery-reared releases, or wild fish (WILD), or age-4 hatchery-reared releases (AGE4) in the lower 152 km of the Chena River.

Variance of the proportion was approximated with the formula for the quotient of two dependent variables (Bernard 1983):

$$\hat{V}\left[\hat{p}_{AGEx}\right] \approx \hat{p}^2_{AGEx} \cdot \left(\frac{\hat{V}\left[\hat{N}_{AGEx}\right]}{\hat{N}^2_{AGEx}} + \frac{\hat{V}\left[\hat{N}_{ALL}\right]}{\hat{N}^2_{ALL}} - \frac{2\hat{V}\left[\hat{N}_{AGEx}\right]}{\hat{N}_{AGEx}\hat{N}_{ALL}} \right). \tag{13}$$

ESTIMATION OF SURVIVAL AND RECRUITMENT

As of 1996, 11 years of population abundance and age composition estimates had been completed for the lower 152 km of the Chena River. Using data from 1986 through 1995, Clark (1996) reported on survival rates and recruitment for 1986 through 1995. Survival rate and recruitment for 1996 was calculated in the same manner.

Annual recruitment was defined as the number of age-3 Arctic grayling added to the population between year *t* and year *t+1*, and alive in year *t+1*. Estimates of recruitment were simply the estimates of abundance of age-3 Arctic grayling in 1995 and 1996. Variance of the recruitment estimates were the variance of abundance at age-3 for these same years.

With recruitment and abundance at age estimates in years *t* and *t+1*, the estimate of survival rate between year *t* and year *t+1* was:

$$\hat{S}_{t,t+1} = \frac{\hat{N}'_{t+1}}{\hat{N}_t} \tag{14}$$

where: $\hat{N}'_{t+1} = \sum_{k=4}^{12} \hat{N}_{t+1,k}$ = the abundance of age *k* and older Arctic grayling in year *t*+1; and,

$\hat{N}_t = \sum_{k=3}^{12} \hat{N}_{t,k}$ = the abundance of age *k* and older Arctic grayling in year *t*.

The variance of annual survival was approximated as the variance of a quotient of two independent variables with the delta method (Seber 1982):

$$\hat{V}\left[\hat{S}\right] \approx \left[\frac{\hat{N}'_{t+1}}{\hat{N}_t}\right]^2 \left[\frac{\hat{V}\left[\hat{N}'_{t+1}\right]}{\hat{N}'^{2}_{t+1}} + \frac{\hat{V}\left[\hat{N}_t\right]}{\hat{N}_t^2}\right] \tag{15}$$

where: $\hat{V}\left[\hat{N}'_{t+1}\right] = \sum_{k=4}^{12} \hat{V}\left[\hat{N}'_{t+1,k}\right]$;and, $\hat{V}\left[\hat{N}_t\right] = \sum_{k=3}^{12} \hat{V}\left[\hat{N}_{t,k}\right]$.

HISTORIC DATA SUMMARY

Data collected from the Chena River (1955 to 1995) were summarized in Appendix B. Creel survey estimates, population abundance estimates, length at age estimates, age composition estimates, size composition estimates, and a model of Arctic grayling growth were summarized from Federal Aid in Sport Fish Restoration reports and State of Alaska Fishery Data Series reports written from 1959 to 1995 (Appendix B). When possible, estimates of precision were reported with point estimates. Precision was reported as either standard error or 95% confidence interval. Sample sizes were reported if neither of these estimates of precision were available. Length frequency was generally reported in the literature as numbers sampled per 10 mm length increment. The length frequency distributions were converted into the RSD categories of Gabelhouse (1984) for comparison with data collected from 1986 to 1995. In addition to the aforementioned reports in Appendix B, Arctic grayling migration studies were summarized in a report by Tack (1980). Reports concerning Arctic grayling research from 1952-1980 were compiled by Armstrong (1982). Armstrong et al. (1986) have compiled a bibliography for the genus *Thymallus* to 1985. In addition, Clark (1992b) estimated age and size at maturity for the Chena River stock in 1991 and 1992, and Clark (1993) estimated interannual intrastream movements of tagged fish in the Chena River for 1987 through 1992. A list of electronic data files used in analyses for 1996 are found in Appendix C.

RESULTS

LOWER CHENA SECTION

The Lower Chena experiment was performed during 8 through 18 July 1996 and 3,294 Arctic grayling were captured. Seventy-four immediate mortalities or serious injuries were recorded for an injury rate of 2.3%. A total of 978 fish were marked and released, 2,247 fish were examined for marks, and 143 fish were recaptured during the mark-recapture sampling. No area stratification of the Lower Chena was necessary since recapture-to-catch ratios did not vary significantly among four areas (χ^2 = 1.91, df = 3, P ≈ 0.59; Figure 4). Catch ratios of wild fish versus age-3 and age-4 hatchery-reared fish were not significantly different (χ^2 = 1.27, df = 2, P ≈ 0.53) so that mark-recapture data from all groups could be combined for further analysis. Based on comparisons of length frequencies of marked fish with length frequencies of recaptured fish, there was no significant size selective sampling in the Lower Chena (D = 0.07, P ≈ 0.64; Figure 5) and no size stratification of the data was necessary. The abundance of fish ≥150 mm FL in the Lower Chena was 15,268 (SE = 1,226, Table 2). Abundance of wild fish was 14,643

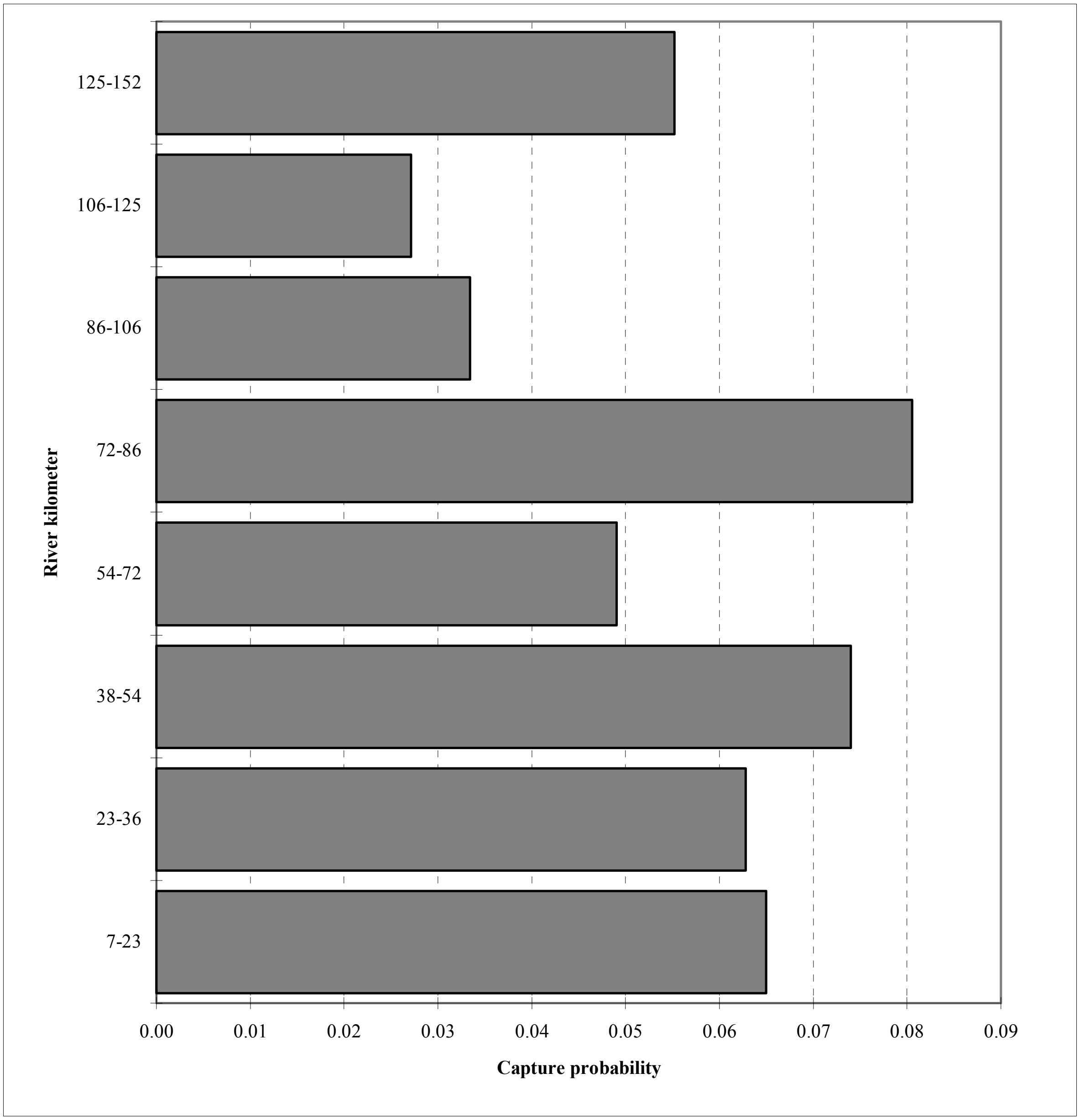
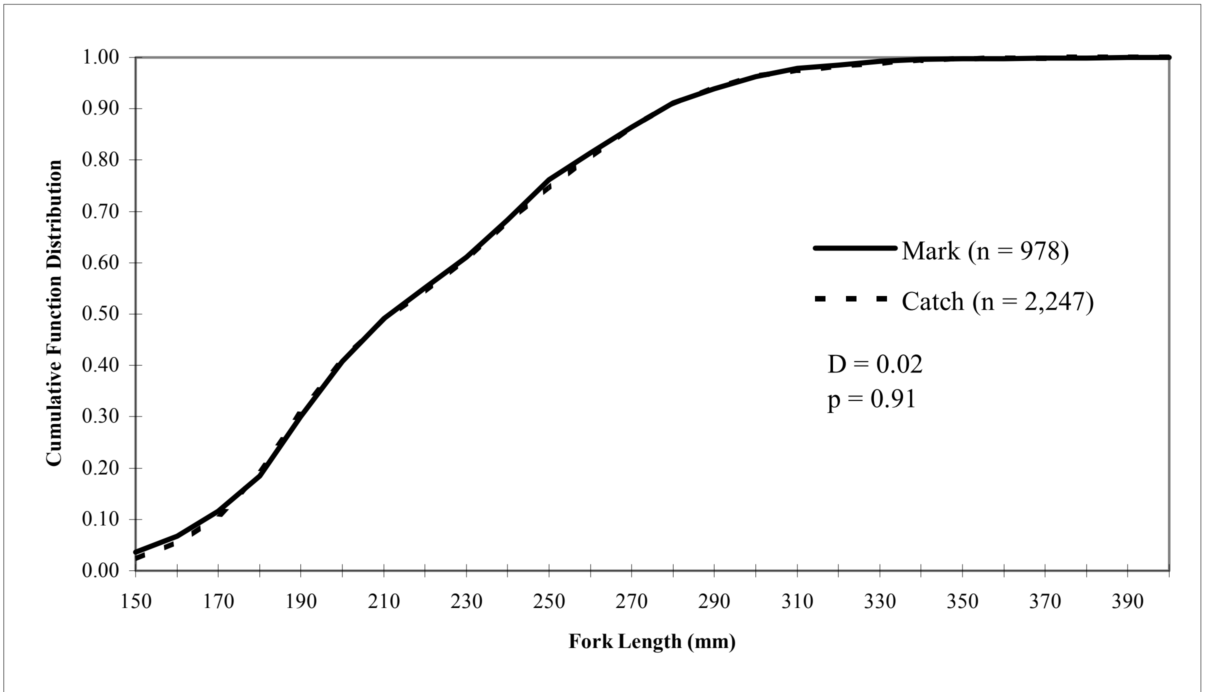


Figure 4.-Recapture-to-catch ratios of Arctic grayling (≥ 150 mm FL) in eight reaches of the Chena River in 1996.



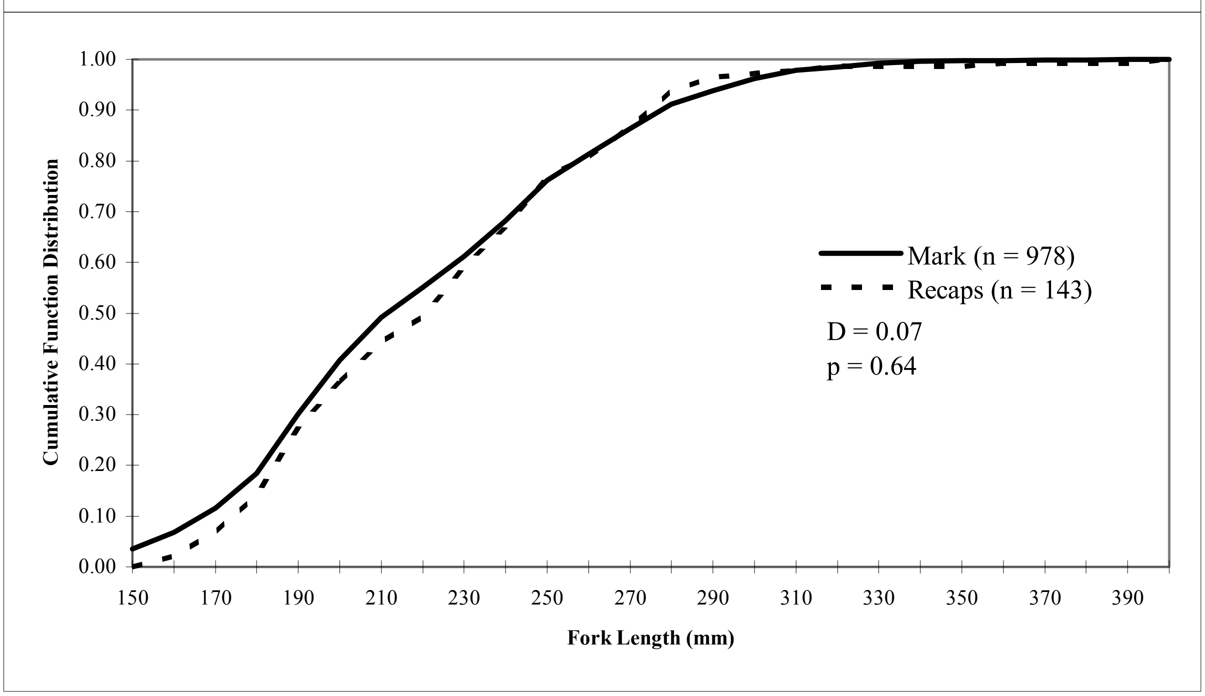


Figure 5.-Cumulative density functions of fork length of Arctic grayling marked, captured, and recaptured in the Lower Chena section of the Chena River, 8 through 18 July 1996.

Table 2.-Capture probabilities and estimated abundance used for population estimation of Arctic grayling (≥ 150 mm FL) in the Lower and Upper Chena sections of the Chena River study area, 8 through 18 July 1996.

Section	Stratum	Mark(n_1)	Catch(n_2)	Recap(m_2)	m_2/n_2[a]	N[b]	SE[N][c]
Lower	NA[d]	978	2,247	143	0.06	15,268	1,226
Upper	small[e]	660	792	25	0.03	20,130	3,810
	large[f]	439	661	38	0.06	7,452	1,143
	Total	1,099	1,453	63	0.04	27,582	3,978

[a] m_2/n_2 is the probability of capture.

[b] N is the estimated abundance in a stratum.

[c] SE[N] is the standard error of N.

[d] NA = not applicable.

[e] small is fish 150 - 284mm FL.

[f] large is fish >284mm FL.

(SE = 1,178) and abundance of age-3 hatchery-reared fish was 183 (SE = 38) or 1.2% of the combined abundance (Table 3). Abundance of age-4 hatchery-reared fish was 442 fish (SE = 64 fish) or 2.9% of the combined abundance (Table 3). There was no significant difference in the length frequencies of fish marked versus those examined for marks in the Lower Chena section ($D = 0.02$, $P \approx 0.91$; Figure 5). Therefore samples from both events could be used to estimate age composition of wild fish and size compositions of wild and hatchery-reared fish. However, samples of ages were only taken during the second event so that age and size compositions were estimated from the second (recapture) event only. Wild age 3 fish were the most abundant age-class comprising an estimated 44% of the population (Table 4). Ages 2 through 5 comprised 79% of the total abundance with very few fish older than age-7. Similarly, stock size wild fish comprised 81% of the abundance in the Lower Chena while 1% of fish were of preferred size (Table 5). Size composition of age-3 hatchery fish (n = 37 from both events) ranged from 215 to 275 mm FL with a mean length of 239 mm FL (SD = 16, Table 6). Size composition of age-4 hatchery fish (n = 90 from both events) ranged from 191 to 305 mm FL with a mean length of 259 mm FL (SD = 20, Table 6).

UPPER CHENA SECTION

The Upper Chena experiment was conducted from 10 through 18 July 1996 and captured 2,565 Arctic grayling. Twenty-six immediate mortalities or serious injuries were recorded for an estimated injury rate of 1.0%. During the mark-recapture sampling, a total of 1,099 fish were marked and released and a total of 1,453 fish were examined for marks of which 63 fish were recaptures. Recapture-to-catch ratios significantly differed among four areas of the Upper Chena ($\chi^2 = 10.61$, df = 3, $P \approx 0.01$; Figure 4). However, the sum of abundance estimates from the four area strata (24,236) did not differ markedly from the unstratified estimate of abundance (24,968). Therefore, abundance, and age and size compositions were estimated for all four areas combined. Catch ratios of wild fish versus age-3 and age-4 hatchery-reared fish in the two events (runs 8 - 30 only) were not significantly different ($\chi^2 = 1.68$, df = 3, $P \approx 0.64$) so that mark-recapture data from all groups could be combined for further analysis. There was a significant difference in length frequencies of fish marked versus those recaptured ($D = 0.28$, $P \approx 0.02$; Figure 6) inferring size selective bias. The maximal chi-squared statistic occurred at a stratification of 150 to 284 mm Fl for small fish and > 284 mm Fl for large fish. Summing the estimates from the small and large fish strata, the estimate of total abundance in the Upper Chena was 27,582 fish (SE = 3,978 fish; Table 2). There were 1.8% age-3 hatchery-reared fish in the small fish stratum and 0.5% age-3 hatchery-reared fish in the large fish stratum (Table 3). There were 1.5% age-4 hatchery-reared fish in the small fish stratum and 0.9% age-4 hatchery-reared fish in the large fish stratum (Table 3). Abundance of wild fish was 26,820 fish (SE = 3,856 fish) and abundance of age-3 hatchery-reared fish was 390 fish (SE = 95 fish) or 1.4% of the combined abundance (Table 3). Abundance of age-4 hatchery-reared fish was 373 fish (SE = 107 fish) or 1.4% of the combined abundance (Table 3).

There was a significant difference in length frequencies of fish marked versus those examined for marks ($D = 0.14$, $P \approx 1E\text{-}6$; Figure 6). Therefore age and size compositions needed correction for changes in capture probability. Since stratified and unstratified abundance estimates were dissimilar (27,582 and 24,968, respectively), only the second event sample was used to estimate compositions. While 11 age classes were present in the Upper Chena, wild age-3, age-5 and age-

Table 3.-Estimates of apportioned abundance in three strata used for population estimation of wild, age-3 hatchery-reared, and age-4 hatchery-reared Arctic grayling (≥ 150 mm FL) in the Lower and Upper Chena sections of the Chena River, 8 through 18 July 1996.

		Upper Chena			Chena River
	Lower Chena	150-284 mm	>284 mm	All	Total
Catch:[a]					
AGE3:	27	14	3	17	44
AGE4	65	12	6	18	83
Wild	2,155	766	652	1,418	3,573
All	2,247	792	661	1,453	3,700
p_{AGE3}[b]	0.012	0.018	0.005	0.012	0.012
SE	0.002	0.005	0.003	0.003	0.002
p_{AGE4}[b]	0.029	0.015	0.009	0.012	0.022
SE	0.004	0.004	0.004	0.003	0.002
Abundance:[c]					
AGE3	183	356	34	390	573
SE	38	93	19	95	102
AGE4	442	305	68	373	815
SE	64	103	29	107	125
Wild	14,643	19,469	7,351	26,820	41,463
SE	1,178	3,687	1,128	3,856	4,032
All	15,268	20,130	7,452	27,582	42,850
SE	1,226	3,810	1,143	3,978	4,163

a Catches are of age-3 hatchery-reared fish (AGE3), age-4 hatchery-reared fish (AGE4), wild fish (Wild), and all fish (All).

b pAGEx is the proportion of age-x hatchery-reared fish in the catches of All fish (AGEx divided by All).

c Abundances are of age-3 hatchery-reared fish (AGE3), age-4 hatchery-reared fish (AGE4), wild fish (Wild), and all fish (All).

Table 4.-Estimates of age composition, length at age, and abundance by age class with standard errors for wild Arctic grayling (≥ 150 mm FL) captured by pulsed-DC electrofishing from the Lower Chena section of the Chena River, 8 through 18 July 1996.

	Age composition			Length at age (mm FL)				Abundance		
Age	n[a]	p[b]	SE	Mean	SD	Min	Max	N[c]	SE[N]	CV
2	140	0.07	0.01	166	16	150	266	1,078	122	11.3%
3	838	0.44	0.01	197	17	154	296	6,455	544	8.4%
4	272	0.14	0.01	235	21	190	305	2,095	204	9.7%
5	254	0.13	0.01	252	17	198	304	1,957	193	9.9%
6	175	0.09	0.01	268	16	226	310	1,348	144	10.7%
7	112	0.06	0.01	282	14	245	342	863	104	12.0%
8	62	0.03	0.00	302	17	261	340	478	70	14.6%
9	29	0.02	0.00	317	15	282	346	223	44	19.7%
10	11	0.01	0.00	332	13	312	358	85	26	30.4%
11	7	0.00	0.00	351	21	315	377	54	20	37.7%
12	1	0.00	0.00	401	---	401	401	8	8	97.9%
Total	1901			228	43	150	401	14,643	1,178	8.0%

a n = number of Arctic grayling sampled at age.

b p = estimated proportion of Arctic grayling at age in the population.

c N = estimated population abundance of Arctic grayling at age.

Table 5.-Summary of Relative Stock Density (RSD) indices of wild Arctic grayling (≥ 150 mm FL) captured in A: the Lower Chena section, B: the Upper Chena section, and C: the Chena River study area, 1996.

		RSD category[a]				
		Stock	Quality	Preferred	Memorable	Trophy
A:	Number sampled	1,741	383	25	0	0
	RSD	0.81	0.18	0.01	---	---
	SE(RSD)	0.01	0.01	<0.01	---	---
	N	11,863	2,610	170	0	0
	SE(N)	962	242	36	---	---
B:	Number sampled	615	675	128	0	0
	RSD	0.43	0.48	0.09	---	---
	Adjusted RSD[b]	0.58	0.36	0.05	---	---
	SE(RSD)	0.04	0.03	0.01	---	---
	N	15,611	9,764	1,445	0	0
	SE(N)	2,970	1,203	250	---	---
C:	Number sampled	2,356	1,058	153	0	0
	RSD	0.66	0.30	0.04	---	---
	Adjusted RSD[b]	0.66	0.30	0.04	---	---
	SE(RSD)	0.02	0.02	0.01	---	---
	N	27,474	12,374	1,616	0	0
	SE(N)	3,121	1,226	252	---	---

[a] Minimum lengths for RSD categories are (Gabelhouse 1984): Stock - 150 mm FL; Quality - 270 mm FL; Preferred - 340 mm FL; Memorable - 450 mm FL; and, Trophy - 560 mm FL.

[b] Adjusted RSD is the RSD corrected for differential vulnerability by length from electrofishing. Standard error of RSD is for the adjusted estimate.

Table 6.-Length composition of age-3 (1993 brood) and age-4 (1992 brood) hatchery reared Arctic grayling in the Lower and Upper Chena sections of the Chena River study area, July 1996.

Brood	Area	n	mean	SD	Min	Max
1992	Lower Chena	90	259	20	191	305
1992	Upper Chena	27	275	22	238	321
	Both	117	262	21	191	321
1993	Lower Chena	37	239	16	215	275
1993	Upper Chena	23	257	18	219	293
	Both	60	246	19	215	293

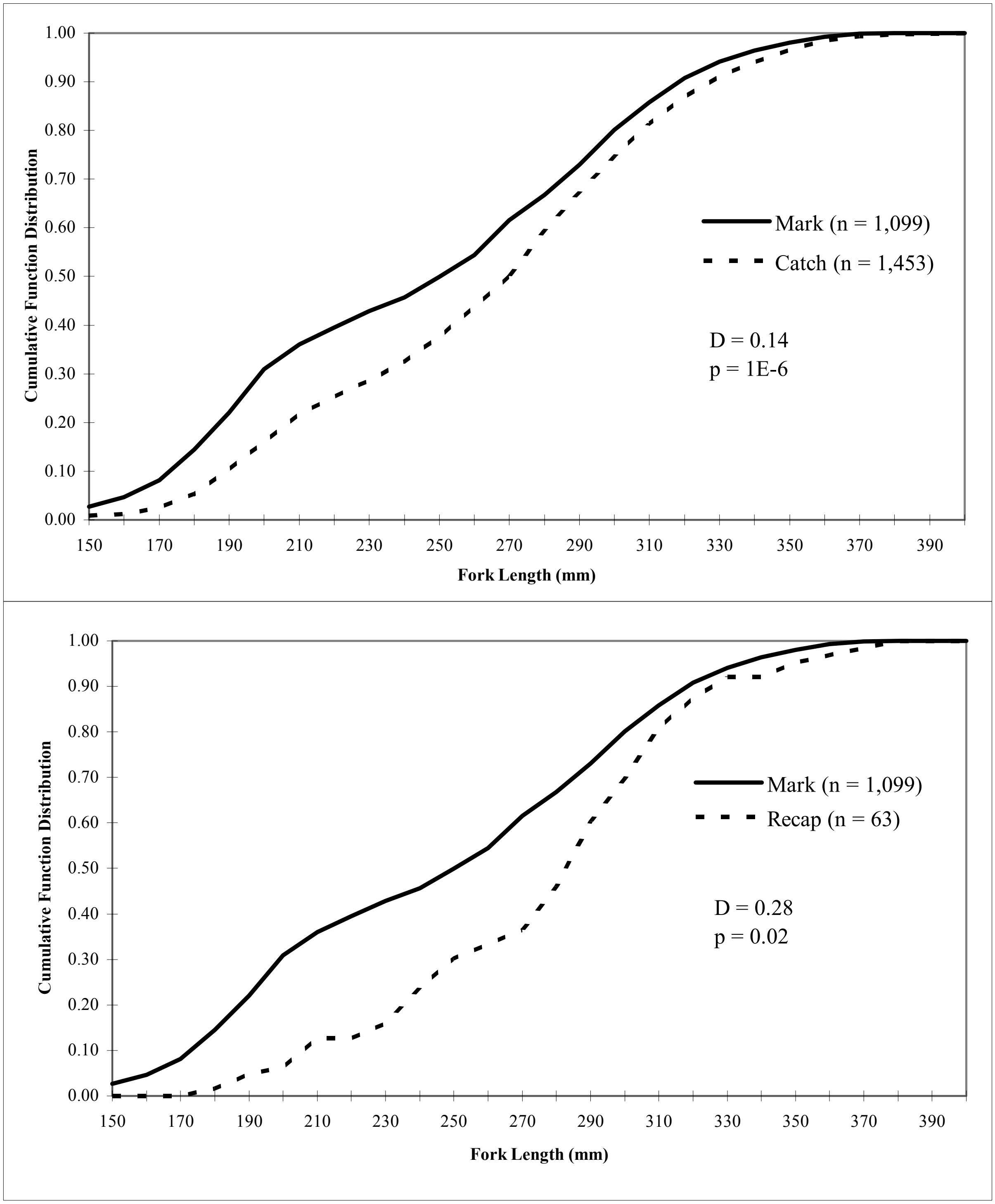


Figure 6.-Cumulative density functions of fork length of Arctic grayling marked, captured, and recaptured in the Upper Chena section of the Chena River, 10 through 18 July 1996.

6 fish were the most abundant comprising 68% of the abundance (Table 7). Stock size fish (150 - 270 mm FL) comprised 58% of abundance while 5% of fish were of preferred size (Table 5). Lengths of hatchery fish were larger than those in the Lower Chena. Lengths of age-3 hatchery fish (n = 23 from both events) ranged between 219 and 293 mm FL with a mean of 257 mm FL c (SD = 18, Table 6). Lengths of age-4 hatchery fish (n = 27 from both events) ranged between 238 and 321 mm FL with a mean of 275 mm FL (SD = 21, Table 6).

CHENA RIVER

Summing estimated abundances from the Lower and Upper Chena sections, there were 41,463 wild fish (SE = 4,032 fish), 573 age-3 hatchery-reared fish (SE = 102 fish), and 815 age-4 hatchery-reared fish (SE = 125 fish) in the lower 152 km of the Chena River in July of 1996 (Table 3). The overall proportion of hatchery-reared fish was 0.03 (SE = 0.01) or 3.2%. Age-3 hatchery-reared fish comprised 1.3% (0.01, SE < 0.01) and age-4 hatchery-reared fish comprised 1.9% (0.02, SE = 0.01) of total abundance. Age-3 fish comprised 38% of the estimated abundance of wild fish, with age-5 and age-6 fish accounting for 31% of abundance (Table 8). Sixty-six percent of the estimated abundance was of stock size fish, with only 4% of preferred size (Table 5). Abundance of age-3 and older fish was 39,858 fish (SE = 2,282 fish; Table 9). Survival rate of age-3 and older fish from 1995 to 1996 was 0.78 (SE = 0.07; Table 9). Recruitment from 1995 to 1996 (age-3 fish) was 15,605 fish (SE = 1,851 fish, Table 9).

Estimated survival of age-3 hatchery-reared fish from time of release in June 1994 (61,435 fish) to time of stock assessment in July 1996 was 0.01 (SE = <0.01). Annual survival of age-3 hatchery-reared fish (July 1995 to July 1996) was 0.25 (SE = 0.01). Lengths of age-3 hatchery-reared fish ranged between 215 and 293 mm FL (Table 6, Figure 7). Average length of age-3 hatchery-reared fish during stock assessment was 246 mm FL (SD = 19 mm FL, Table 6). Annual survival of age-4 hatchery-reared fish (July 1995 to July 1996) was 0.40 (SE = 0.02). Lengths of age-4 hatchery-reared fish ranged between 191 and 321 mm FL (Table 6, Figure 7). Average length of age-4 hatchery-reared fish during stock assessment was 262 mm FL (SD = 16 mm FL, Table 6).

DISCUSSION

STOCK STATUS

During the past ten years (1987 through 1996), the present sampling methodology for assessing the status of Chena River Arctic grayling has provided accurate and precise estimates of abundance, composition, and dynamic rates. The methodology was implemented to allow managers to accurately assess the population's response to restrictive regulations designed to stem the decline in harvest and the declining trend in abundance of "index" areas in the mid 1980's (Clark 1986). Between 1987 and 1991, population response to the first "set" of restrictive regulations (see Introduction) was to an increase in annual survival rate (Clark 1991, 1993; Table 9). Annual abundance languished between 16,236 and 29,580 fish aged 3 and greater while the number of spawners decreased (Table 9, Figure 8). Annual recruitment was less than 4,400 fish in four of the five years but averaged 6,778 fish annually (SE = 2,125 fish, Table 9) which barely replaced the average annual harvest of 5,611 fish (from Table 1). In the five years since 1991 when regulations changed to a no harvest policy, the survival rate rose to an annual

Table 7.-Estimates of adjusted age composition, length at age and abundance by age class with standard errors for wild Arctic grayling (≥150 mm FL) captured by pulsed-DC electrofishing from the Upper Chena section of the Chena River, 8 through 18 July 1996.

	Age Composition				Length At Age (mm FL)				Abundance		
Age	n[a]	p[b]	p'[c]	SE[p']	mean	SD	Min	Max	N[d]	SE[N]	CV[e]
2	18	0.02	0.02	0.00	165	12	150	191	527	157	30%
3	313	0.28	0.34	0.03	205	17	155	307	9,151	1,780	19%
4	85	0.08	0.09	0.01	241	14	210	280	2,489	535	22%
5	184	0.16	0.18	0.01	270	19	229	325	4,878	876	18%
6	196	0.18	0.16	0.01	288	18	233	344	4,316	627	15%
7	110	0.10	0.08	0.01	301	16	258	350	2,020	310	15%
8	93	0.08	0.06	0.01	321	16	291	388	1,509	270	18%
9	58	0.05	0.04	0.01	327	19	285	383	941	184	20%
10	37	0.03	0.02	0.01	342	21	299	394	600	131	22%
11	17	0.02	0.01	0.00	359	23	321	402	276	78	28%
12	7	0.01	0.00	0.00	360	21	332	394	114	46	40%
Total	1,118	1.00	1.00	---	272	52	150	402	26,820	3,856	14%

a n = number of Arctic grayling sampled at age.

b p = estimated proportion of Arctic grayling at age in the sample.

c p’ = estimated adjusted proportion of Arctic grayling at age in the population.

d N = estimated population abundance of Arctic grayling at age.

e CV = coefficient of variation.

Table 8.-Estimates of adjusted age composition and abundance by age class with standard errors for wild Arctic grayling (≥ 150 mm FL) captured by pulsed-DC electrofishing from the Chena River, 8 through 18 July 1996.

Age	p[a]	SE	N[b]	SE
2	0.04	<0.01	1,605	199
3	0.38	0.02	15.605	1,851
4	0.11	0.01	4,584	571
5	0.17	0.01	6,834	892
6	0.14	0.01	5,664	641
7	0.07	0.01	2,883	327
8	0.05	0.01	1,987	279
9	0.03	0.01	1,165	189
10	0.02	<0.01	685	134
11	0.01	<0.01	330	80
12	<0.01	<0.01	121	46
Total	1.00	---	41,463	4,032

a p = estimated adjusted proportion of Arctic grayling at age in the population.

b N = estimated population abundance of Arctic grayling at age.

Table 9.-Summary of population abundance, annual survival (%), annual recruitment, and standard error estimates during 1987-1996 for wild Arctic grayling (≥ age-3) in the lower 152 km of the Chena River.

Year	N[a]	SE	S[b]	SE	B[c]	SE
1987	29,580	3,525	57.1	8.1	2,526	358
1988	20,268	1,214	58.7	9.0	3,373	529
1989	16,236	1,618	75.4	11.0	4,332	491
1990	29,130	4,373	74.7	13.2	16,881	4,172
1991	24,657	2,082	78.8	8.2	2,882	368
1992	25,211	1,333	60.1	6.2	5,773	591
1993	34,209	2,969	76.9	7.8	19,066	2,647
1994	39,414	1,834	62.6	5.4	13,113	1,183
1995	31,016	1,922	78.2	6.5	6,326	747
1996	39,858	2,282			15,605	1,851
Averages[d]:	28,958	2,507	68.9	8.1	8,988	1,759
1987-1990:	23,804	2,985	65.9	10.1	6,778	2,125
1991-1996:	32,394	2,129	70.8	6.7	10,461	1,465

[a] N is the abundance of age-3 and older Arctic grayling.

[b] S is the survival from that year to the next year.

[c] B is recruitment of age-3 Arctic grayling during that year.

[d] Average of survival rate is the geometric mean.

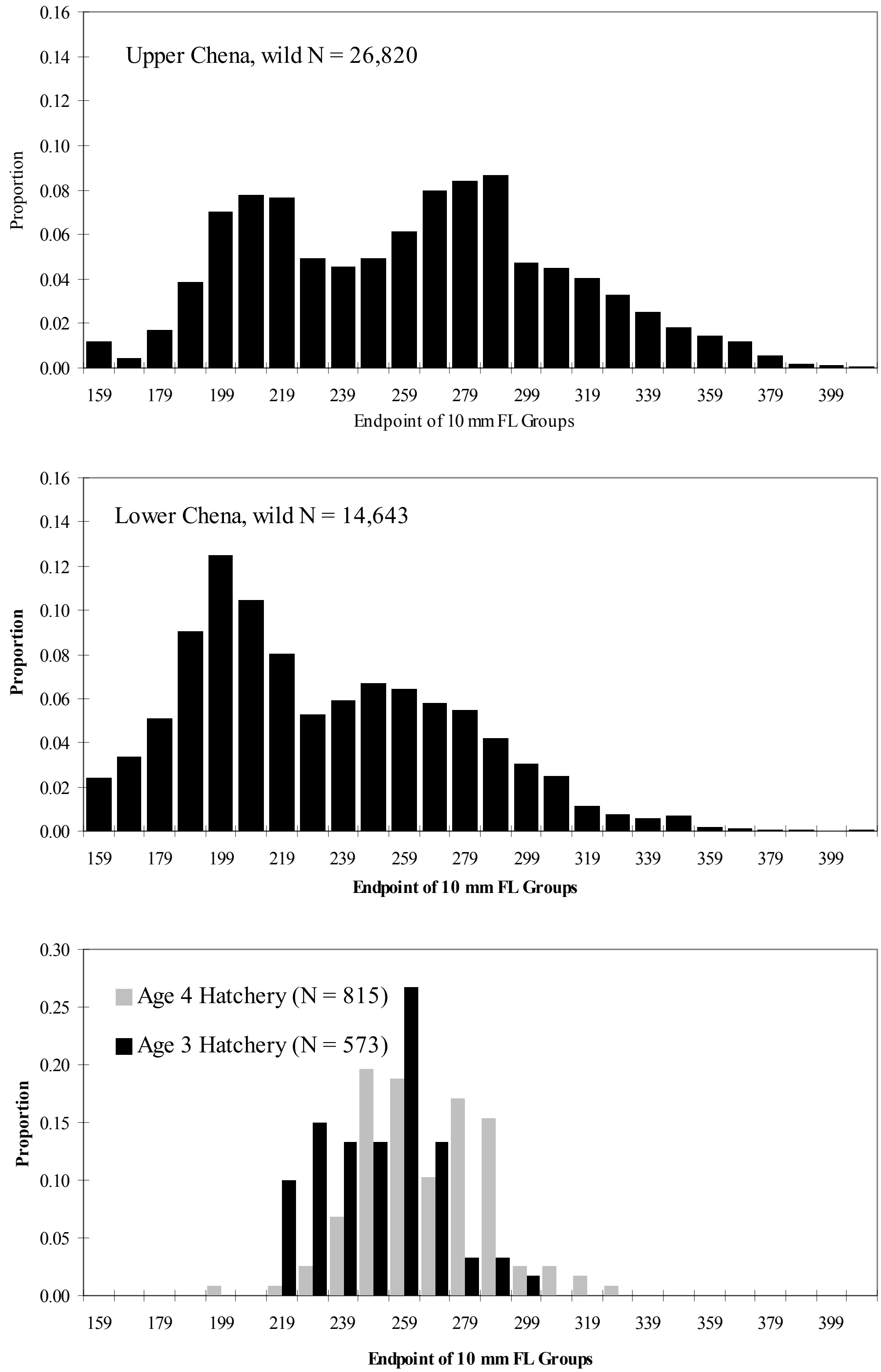


Figure 7.-Length composition of age-3 and age-4 hatchery-reared, and wild Arctic grayling during stock assessment in 1996.

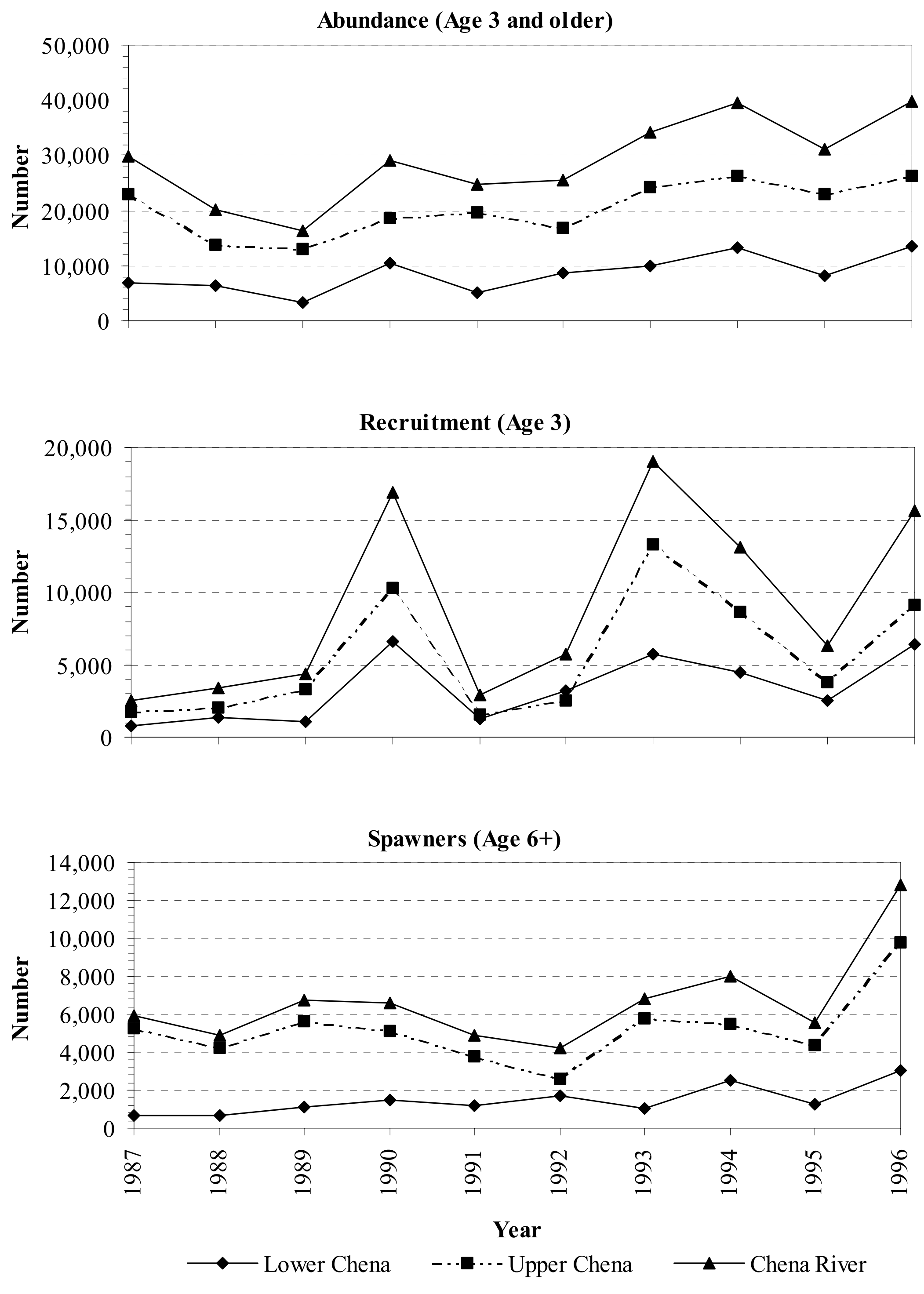


Figure 8.-Estimates of abundance, recruitment, and number of spawners for wild Arctic grayling in the Lower and Upper Chena sections and Chena River study area, 1987-1996.

average of 71% versus 66% for the previous five years (1987-1991; Table 9). Abundance of age 3 fish during this period increased from 24,657 fish in 1991 to 39,858 fish in 1996, the highest level in 10 years (Table 9). While the no harvest policy undoubtedly contributed to the population's growth during the period, the more significant factor was the high level of recruitment. Recruitment in three of the five years from 1992 to 1996 was greater than 13,000 fish (average of 10,461 fish, SE = 1,465 fish; Table 9, Figure 8). The end product of this large recruitment, specifically the recruitment in 1990 and 1993, was the large increase in spawners, fish aged 6 and older, which climbed from less than 8,000 fish in 1987 through 1995 to over 12,000 fish in 1996 (Figure 8). In addition, the large recruitments in 1994 and 1996 should keep spawner abundance at similar levels through 1999. While Clark (1992a) could find no influence of parental stock size on recruitment from a limited analysis, an increase in the number of older, larger spawning individuals in the stock will most likely influence anglers if not the overall size of the population. Indeed, angling effort on the Upper Chena River, which is directed almost exclusively for Arctic grayling (J. E. Hallberg, Alaska Department of Fish and Game, Fairbanks, personal communication) has climbed from a low of 4,983 angler days in 1992 (the first full season of catch and release regulations) to over 13,000 angler days in 1995. With severely restrictive regulations only five years old, this increase in effort is not likely to be just angler response to a larger population of fish but is also quite likely related to a change in angler philosophy and acceptance of the regulations as well.

Although the stock assessment program provides estimates of many parameters necessary for describing stock status on an annual basis, it is but a snapshot of the Arctic grayling resource specific to time and place. While the 152 km long study area comprises 70% of the fished portion of the drainage (Clark 1992a) the sampled area includes only 38% of the total drainage length (approximately 400 km of major tributaries and mainstem). As Tack (1980) and Northcote (1995) note, riverine populations of Arctic grayling are highly migratory. Seasonal habitats vary depending upon age and sexual maturity. We believe that the program's estimates are precise and occur during a time when Arctic grayling movements are minimal. These investigations have indicated that the population in the study area exhibits interannual movements that range from 7% to 24% of the population annually (Clark 1993). It appears larger fish prefer upstream areas and smaller fish prefer downstream areas (Tack 1980, Tables 4, 5 and 7), and that spawning adults are present in the Lower Chena in May and are not there in July (Tack 1980, Clark 1993). There is also evidence that sub-populations exist in some tributary headwaters (Ott and Scanell 1996) which contribute some production to the study area. Even with this level of understanding, there remains the elemental question of what total proportion of the stock does our present program assess and where does this recruitment come from? If prior assessments are based upon a consistent proportion of the total stock and we understand the recruitment levels from other areas; then all years of assessment data would be applicable to population models thereby allowing managers more flexibility to implement regulatory changes to allow for consumptive use. Future research on the Chena River Arctic grayling stock should test the hypothesis that the assessed area is representative of the total drainage stocks and that "outside" recruitment is negligible. Broad-based studies may need to be designed in order to estimate abundance and composition in other areas of the drainage, thereby allowing for estimates of the production of the stock relative to specific areas and the dispersal of this production as the cohorts mature.

HATCHERY-REARED FISH

Hatchery reared fish continued to show survival and growth rates that are inferior to those of wild fish. While low initial (≈60% in the first month) and first year (≈10%) survival rates may be attributable to loss of fish to areas outside the study area (Clark 1995; hatchery reared fish were sampled in Badger Slough in May 1996), ensuing rates should be similar to wild fish provided the remaining fish are fully acclimatized. Hatchery fish from both brood years survived at lower rates in 1996, their second and third year after release, than did wild fish (25% and 40%, respectively for ages-3 and 4 hatchery fish, versus 78% for wild fish, Table 10). While size of hatchery fish approximated that of wild age-3 fish at stocking (≈210 mm versus 198 mm), growth has ranged from 10 to 24 mm per year versus 25 to 32 mm per year for similar age-classes wild fish (Table 10 and Appendix B2, respectively). The distinct coloration noted for hatchery fish in the first and second years after stocking (Clark 1994, 1995) persisted in 1996 but Fewer individual fish appeared to be affected. As this data suggests and Clark (1996) noted, the utilization of hatchery supplementation in a non-consumptive fishery was ineffectual and not cost effective. In a consumptive fishery, benefits could accrue from enhancement given the hatchery fish are of a large size at release and there is sufficient angling effort to remove the majority of fish in the first year of each stocking. Clark also noted no short term deleterious effects in the wild population from the program. Provided that the brood stock is endemic to the drainage, this method of enhancement could provide greater opportunity in those waters lacking surplus production and having a consumptive demand.

ACKNOWLEDGMENTS

The author extends thanks to the following people for their expertise and enthusiasm in the field: the upper Chena crew of Doug Fleming, David Cox; and Richard Bettinger; the lower Chena crew of James Fish, Roy Perry, Brendan Scanlon, Jerry Hallberg, Michael Daigneault, Mike Wallendorf, John Burr, Don Roach, Klaus Wuttig, Mark Ross, and Shaun Fairhead. Special thanks goes to Robert Clark, former project leader, who developed the sampling and statistical methodology that has resulted in a database unsurpassed in Arctic grayling population dynamics. Fred Andersen and Margaret Merritt are thanked for providing the administrative structure necessary for implementing this project. Mike Wallendorf provided a biometric review. Thanks also go to Sara Case for editing and printing of this report. This project and report were made possible by partial funding provided by the U.S. Fish and Wildlife Service through the Federal Aid in Sport Fish Restoration Act (16 U.S.C. 777-777K) under project F-10-12, Job Number R-3-2(a).

Table 10.-Summary of abundance, annual survival (%) and standard error estimates for 1992 and 1993 brood years of hatchery reared Arctic grayling stocked at age-1 in the lower 152 km of the Chena River, 1993-1996.

1992 Brood:					Length (mm FL)				
Year	N[a]	SE[N]	S[b]	SE[S]	Mean	SD	Min	Max	Growth[c]
1993[d]	64,936	0	---	---	212	NA	NA	NA	---
1993	33,061	3,190	50.9[e]	0.5	217	21	150	270	5
1994	3,699	307	11.2	0.2	228	18	160	290	11
1995	2,015	283	54.5	1.4	252	16	190	290	24
1996	815	125	40.4	1.7	262	21	191	321	10
1993-1996			1.3[g]	<0.1					50

1993 Brood:					Length				
Year	N	SE[N]	S	SE[S]	Mean	SD	Min	Max	Growth
1994[f]	61,435	0	---	---	208	NA	NA	NA	---
1994	41,928	5,105	68.2[e]	1.0	216	21	198	230	8
1995	2,325	372	5.5	0.2	232	17	200	280	16
1996	573	102	24.6	1.4	246	19	215	293	14
1994-1996			0.9[g]	<0.1					38

[a] N is the abundance.

[b] S is the survival rate (%) from the previous year to that year.

[c] Growth is length increase (mm) from previous sample.

[d] 1992 brood stocked 1-11 June.

[e] The survival rate from stocking to sampling, approximately one month.

[f] 1993 Brood stocked 7-30 June.

[g] Survival from stocking to July 1996.

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APPENDIX A

STOCK ASSESSMENT OF ARCTIC GRAYLING IN BADGER SLOUGH DURING 1996

INTRODUCTION

Badger Slough, originally a silty slough of the Tanana River, was physically blocked during the 1940's and became a clearwater tributary to the Chena River (Hughes 1986). The slough, also known as Chena Slough, was reduced from 27 to 25 km in length after the Chena River Flood Control Project blockage was established. Prior to this, flows varied with the level of the Tanana River and ranged up to 100 m^3/sec (Walker 1983). Its present water source is clear upwelling waters from the Tanana River aquifer. The slough, influenced by low stream gradient and many constrictive road culvert crossings, moves slowly in a northwestern direction before emptying into the Chena River at river kilometer 34 (see Figure 1.). Hughes (1986) estimated the slough's discharge between 1.5 and 2.0 m^3/sec. Hydrologically, the slough is unlike spring-fed and rapid run-off streams and rivers in the area. Water temperature at Badger Slough fluctuates substantially through the season and throughout the day (Wuttig 1997), unlike the Delta Clearwater and other spring-fed streams (Wojcik 1955, Tack 1980). Fish that have colonized the clearwater slough have included Arctic grayling, northern pike *Esox lucius*, burbot *Lota lota*, humpback whitefish *Coregonus pidschian,* least cisco *Coregonus sardinella,* round whitefish *Prosopium cylindraceum*, longnose suckers *Catostomus catostomus*, slimy sculpin *Cottus cognatus*, and juvenile chinook salmon *Oncorhynchus tshawytscha*. The combination of nearly-constant flow, low velocity (low gradient), and the generally early spring breakup and seasonably warm water conditions created suitable habitat for Arctic grayling spawning and rearing.

Early accounts of angling pressures within the Tanana drainage mentioned the Arctic grayling sport fishery at Badger Slough in 1952 (Wojcik 1952). Since 1956, Badger Slough has been recognized as having one of the earliest spring Arctic grayling migrations and spawning periods in the drainage (Warner 1957). In that year, the onset of the Arctic grayling immigration was in early April, and fish had reached spawning condition by the end of the month. In 1967, a creel survey documented the size of the Arctic grayling fishery at Badger Slough. In that year, anglers spent an estimated 4,185 angler days at Badger Slough, while only 3,900 angler days were spent in areas of the Chena River accessed by the Chena Hot Springs Road (Van Hulle 1968). In 1973, Tack inferred the presence of a large number of spawning Arctic grayling in Badger Slough based on size compositions (Tack 1973). From 1967 through 1975, spring harvests at Badger Slough ranged from 2,669 to 9,958 Arctic grayling (Tack 1976). Assessment of Arctic grayling in Badger Slough has been attempted several times using weirs in 1975 (Tack 1976) and 1985 (Hughes 1986). In both years, April ice conditions prevented the successful operation of the weirs and estimation of spring abundances.

Because of its upwelling water source, it is likely that Badger Slough may provide greater protection and spawning success for Arctic grayling than in the mainstem Chena River in years of high post-spawning flows. Clark (1992a) found significant relationships between estimated recruitment levels and the flow conditions in the natal year for fish within the Chena River. Because post-spawning Arctic grayling in Badger Slough are believed to return to the Chena River, it has been assumed that the relative abundance of the spring Arctic grayling stock in Badger Slough was indicative of the Chena River stock assessed each July. In 1995, a stock assessment project was implemented at Badger Slough using a mark-recapture approach with electrofishing similar to efforts at Piledriver Slough (Clark 1996). Unfortunately, the window of opportunity for sampling precluded the estimation of abundance, and biased age and size composition estimates (Clark 1996).

In 1996, an assessment of the Arctic grayling stock was needed at Badger Slough. The assessment was integral to a cooperative research study between the Sport Fish Division and University of Alaska, which assessed the limnological and hydrological status of Badger, Piledriver, and Twenty-three Mile Sloughs in relation to production of Arctic grayling (Wuttig *1997*).

OBJECTIVES

The research objectives for 1996 were to:

1. estimate abundance of Arctic grayling (≥150 mm FL) in an 8.8 km section of the Badger Slough, such that the estimate is within 25% of the true abundance 95% of the time;
2. estimate age composition of Arctic grayling (≥150 mm FL) in Badger Slough, such that all proportions are within 5 percentage points of the true proportions 95% of the time;
3. estimate size composition of Arctic grayling (≥150 mm FL) in Badger Slough, such that all proportions are within 5 percentage points of the true proportions 95% of the time; and,
4. estimate the relative contribution of Arctic grayling (≥150 mm FL) that were marked and released at Badger Slough during the spawning period and recovered in the lower 152 km of the mainstem Chena River during July, such that the estimate is within 25 percentage points of the true contribution 95% of the time.

METHODS

In 1995, Clark (1996) attempted to estimate abundance and composition of Arctic grayling (≥150 mm FL) that seasonally inhabit Badger Slough using backpack electrofishing gear. Earlier attempts to assess the stock using weirs (Tack 1976, Hughes 1986) were foiled by problems in maintaining and trapping Arctic grayling beneath the ice. The 1996 assessment of Arctic grayling in Badger Slough used mark-recapture sampling with backpack electrofishing gear; beach seines, and hook and line gear to sample in areas not conducive to backpack electrofishing. Beach seining was conducted at suitable locations where fish were concentrated and where seines could be effectively fished. Hook and line sampling was used primarily in areas too deep for electrofishing crews and where woody, vegetative and detrital debris created problems for beach seining.

Mark-recapture sampling of Arctic grayling was conducted between 6-17 May, and was originally planned for a 8.8 km section of Badger Slough. This section extended from Persinger Drive crossing upstream to the Plack Road crossing (Figure A1.). Backpack electrofishing crews started sampling on 6 May. At this time, ice cover was still present over most of the Badger Slough study area. During foot surveys, a high beaver dam was located that evidently prevented Arctic grayling from migrating into much of the study section. The dam was located approximately 1 km upstream of the Peede Road crossing and reduced the assessed portion of Badger Slough to 5.7 km, or 23% of the entire slough length. During the marking event, fish

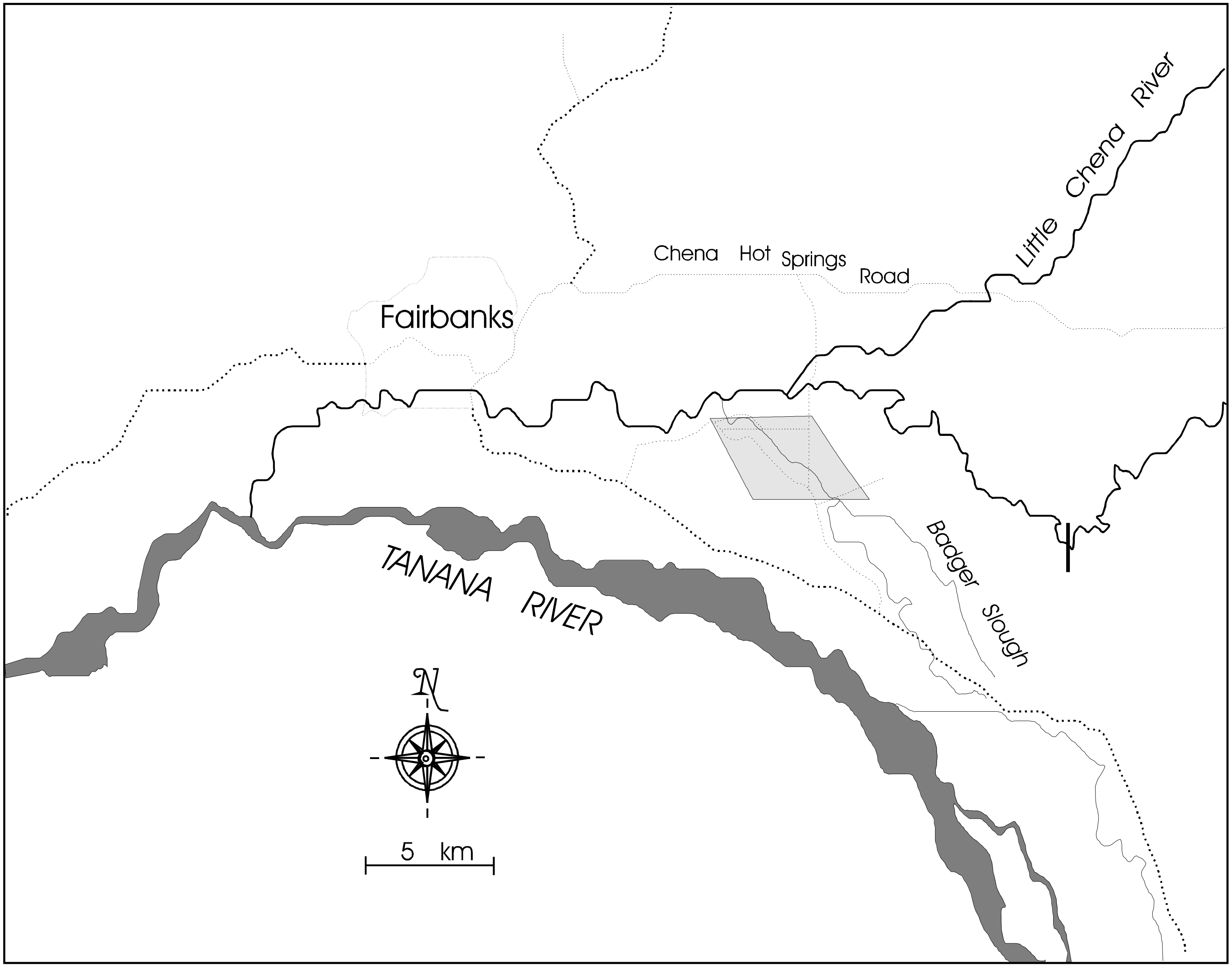

Figure A1.-The lower 72 km of the Chena River, showing the section of Badger Slough that was assessed in 1996.

were captured by hook and line at the Peede Road crossing by staff and local anglers. Following a six-day hiatus, a second sampling event was conducted with backpack electrofishing, beach seining, and hook and line. Sampling extended from Hurst Road (slough kilometer 15.9) downstream to the Persinger Road crossing (slough kilometer 1.3).

Methodology for sampling and parameter estimation (abundance, age, and size compositions) were the same as detailed earlier in this report.

RELATIVE CONTRIBUTION

Contribution of Arctic grayling from a 5.7 km section of Badger Slough in May to the lower 152 km of the Chena River in July was estimated in two parts. First the proportion marked and released in Badger Slough was estimated from mark-recapture data:

$$\hat{p}_t = \frac{m_t}{\hat{N}} \tag{A.1}$$

where: p_t is the estimated proportion released alive in Badger Slough bearing a mark,

m_t is the number marked; and,

$\hat{N}$ is the estimated abundance in Badger Slough during May assessment.

The proportion of fish originally released in Badger Slough that were in the Chena River during July was estimated by:

$$\hat{p}_m = \frac{c_m}{n_m} \tag{A.2}$$

where:

p_m is the estimated proportion of fish in the Chena River that were originally marked in Badger Slough;

c_m is the number bearing a mark from the Badger Slough experiment; and,

n_m is the number examined in the Chena River.

Variance of p_m is the variance of a binomial.

The contribution (p_c) was then estimated from the ratio of these two proportions:

$$\hat{p}_c = \frac{\hat{p}_m}{\hat{p}_t} = \hat{p}_m \hat{N} \frac{1}{m_t}. \tag{A.3}$$

The estimate for the exact variance (Goodman 1960) of p_c is:

$$\hat{V}(\hat{p}_c) = \frac{1}{m_t^2}\left[\hat{N}^2 \hat{V}(\hat{p}_m) + \hat{p}_m^2 \hat{V}(\hat{N}) - \hat{V}(\hat{p}_m)\hat{V}(\hat{N})\right]. \tag{A.4}$$

RESULTS

Since much of Badger Slough was covered by ice during the first sampling event (marking event), fish could only be captured 400 m upstream and 100 m downstream of the Peede Road crossing. Between 6 - 9 May, the six-person crew sampled and released 607 Arctic grayling (≥ 150 mm FL). As many as five sport anglers each day volunteered their catches to the sample. All but 27 fish were captured by hook and line using bait (shrimp), spinners, small plastic and feather jigs, and flies (bead head nymphs, and caddis imitations). Of the remaining 27 fish, eight fish were captured by seine and 19 by electrofishing immediately below the Peede Road crossing. Daily water temperatures ranged from 1.5°C in the morning to 4°C by late afternoon. After sampling, fish were released back into Badger Slough bearing a gray Floy anchor tag, and a partial upper-caudal finclip. Throughout the marking event, staff members observed tagged fish moving upstream through culverts at the Peede Road crossing. Over the course of capturing and sampling fish, nine mortalities occurred, representing 1.4% of the marking event catch.

The second sampling event (referred to as the recapture event) began on 13 May, and because of the slough's nearly complete breakup, sampling encompassed a much larger area. The upstream study boundary was extended upstream 1.8 km when two Arctic grayling were observed at the Hurst Road crossing. The sampling crew proceeded 15.9 km downstream from the Hurst Road crossing to the Persinger Drive crossing. Sampling in Badger Slough was conducted in a discontinuous fashion. Road crossing culverts and beaver dams have created numerous areas that could not be fished effectively with electrofishing gear. Crews used hook and line gear in deep areas with low visibility and the presence of cover. Crews performed visual counts from canoes in areas where the slough was wide, moderately deep, and with little-or-no available cover. The conditions were optimal for visual counting over much of the area. They included bright sun, high water clarity, light colored substrates, and a lack of cover. While no fish were captured by hook and line in deep areas, the electrofishing catches and visual counts were as follows in the 10.1 km section:

Badger Slough sections sampled during second sampling event: {section length}	Electrofishing/Seining Catches	Visual Counts
Hurst Road to Airway Drive {0.83 km}	1	2
Airway Drive to Plack Road {1.04 km}	0	0
Plack Road to Repp Road {3.04 km}	7	5
Repp Road to Nordale Road {4.00 km}	7	0
Nordale Road to impassable beaver dam {1.21 km}	0	0

In total, only 22 Arctic grayling were either captured or observed in the upper portions of the study area. One of the 15 captured fish retained a tag and a finclip from the 1995 sampling, but no other tagged Arctic grayling were captured or observed.

Large numbers of Arctic grayling were found immediately below the large beaver dam located midway between the Nordale Road and Peede Road crossings, or approximately 0.9 km upstream from the Peede Road crossing where the marking event was concentrated. On 14-17 May, crews captured and sampled 703 Arctic grayling between the beaver dam and Persinger Drive. In the course of capturing and sampling fish, sampling mortalities accounted for 1.1% of the sample (four fish from electrofishing, four fish from hook and line). Because marked fish failed to pass upstream of the beaver dam and mix, all further estimates of abundance and composition were germane to the Arctic grayling stock downstream of the beaver dam. Because no fish less than 225 mm FL were recaptured, the mark-recapture data set was truncated to include fish ≥ 220 mm FL. All subsequent estimates in this study (abundance, age and size composition, and relative contribution to the Chena River) included fish above this threshold size. The reduced study area was then subdivided among three (3) reaches.

Sampled Reach	Marks	Catch	Recaps	R/C
2	---	535	32	0.06
3	---	78	5	0.07
4	---	8	1	0.12
Total	547	621	38	

Recapture-to-catch ratios did not vary significantly between the three sample reaches ($\chi2 = 0.59$, $P = 0.74$, $df = 2$). While hook and line was the predominant gear type in the marking event, backpack electrofishing and beach seining gears were used to supplement hook and line catches during the recapture event, particularly near the beaver dam. Recapture event catches were (by gear type):

Gear	Catch	Recaps	R/c
Electrofishing	124	8	0.06
Beach Seine	270	17	0.06
Hook and line	227	13	0.06
Total	621	38	0.06

Recapture-to-catch ratios did not vary significantly between the three gear types used during the recapture event ($\chi2 = 0.09$, $P = 0.95$, $df = 2$).

Kolmogorov-Smirnov tests of cumulative length frequencies from the mark-recapture experiment inferred that size selectivity was present during the recapture sampling event, but selectivity bias was not detected for the marking event (Figure A2.A - mark vs recaptures: $D = 0.28$, $P = 0.007$; and, Figure A2.B - mark vs catch: $D = 0.18$, $P = 2 \times 10^{-8}$). As a result of assumption testing, the abundance of Arctic grayling ≥ 220 mm FL was estimated with both unstratified and stratified approaches (Case IV; Appendix B9). The selected size strata were: 220 to 284 mm FL, and 285 mm FL and larger. This was based on maximal differences in

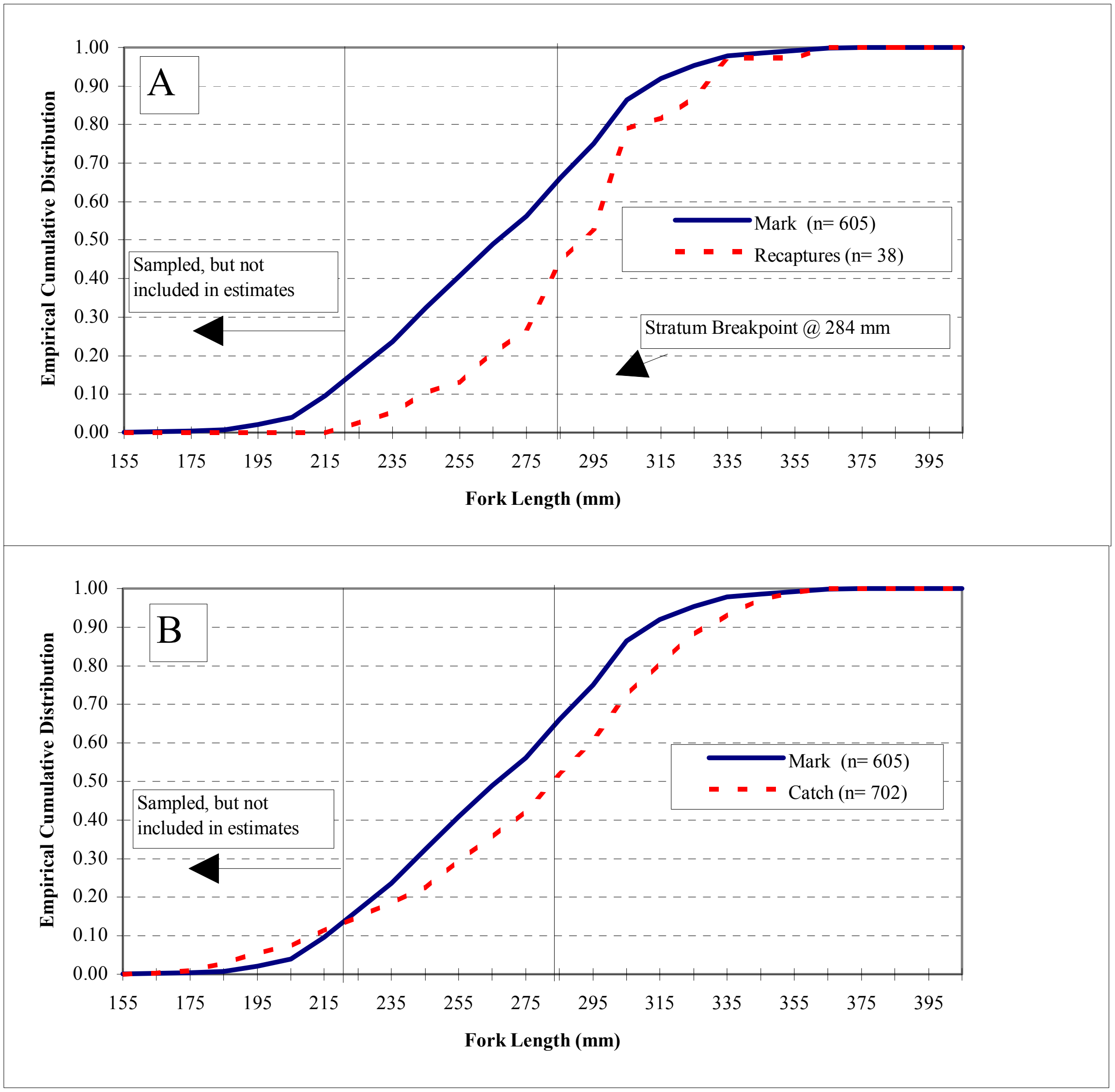

Figure A2.-Empirical cumulative distribution of fork lengths of all sampled Arctic grayling from the mark event versus those recaptured (A), and mark event versus catch event samples (B), from Badger Slough, May 1996. Figures also show selected size for stratification based on iterative series of chi-square tests, and fish sampled but not included in the final estimates of abundance, size, and age composition (fish less than 220 mm FL).

recapture-to-catch ratios among possible strata ($\chi2_{285mm}$ = 11.6, df = 1). Stratified and unstratified estimates of abundance were:

Strata- {size grouping}	Mark M	Catch C	Recap R	Capture Probability	Abundance N-hat	Standard Error
220 to 284 mm FL	313	241	11	0.04	6,312	1,707
≥ 285 mm FL	234	380	27	0.06	3,184	597
Total	547	621	38	----	9,496	1,801
Unstratified	547	621	38	0.06	8,723	1,335

Since the stratified and unstratified estimates were dissimilar, the stratified approach was most appropriate (Appendix B9; case IVa). The estimated abundance of Arctic grayling (≥ 220 mm FL) in the 5.7 km study area was 9,496 fish (SE = 1,801, CV = 19%).

Stock composition estimates were based on the second sampling event (Case IV; Appendix B9) and were adjusted for size selectivity. Therefore, the composition estimates, and the abundance estimates, were specific to Arctic grayling ≥ 220 mm FL. The ages of sampled Arctic grayling ranged from 3 years to 11 years with ages 5 and 6 predominant (Table A1). The median age was 6 years. An estimated 81% of the fish were between 4 and 7 years. Sizes of captured Arctic grayling ranged between 220 and 369 mm, and the size composition was predominated by fish between 250 and 289 mm FL (Table A1). The median length was 293 mm FL. Because of the limited size range of the mark-recapture data, the relative strengths of younger and smaller Arctic grayling could not be estimated.

The relative contribution of fish present in Badger Slough in May that were later present in the Chena River in July was estimated for two size groupings: fish ≥ 220 mm FL, and fish ≥ 270 mm FL and, within the two assessed sections of the Chena River (upper and lower). The latter size grouping equates to a 12 inch total length fish, which was the regulatory minimum for harvest and nearly approximates the length at spawning for 50% of the Chena River population (272 mm FL from Clark 1992b). During the May assessment at Badger Slough 1,130 fish ≥ 220 mm FL, and 729 fish ≥ 270 mm FL were tagged and released during the mark-recapture experiment.

The estimated marked proportion (P_t) for fish ≥ 220 mm FL in Badger Slough was 0.12 (SE =0.022), and 0.15 (SE = 0.015) for fish ≥ 270 mm FL. The estimates of Badger Sough contributions to the assessed portions of the Chena River ranged from 0.01 to 0.12 (Table A2). The overall relative contribution rate estimates indicated 6% of Arctic grayling ≥ 220 mm FL and 4% of fish ≥ 270 mm FL present in July along the 152 km assessed portion of the Chena River were also part of the assessed stock in Badger Slough during May (Table A2).

Table A1.-Estimates of the sampled contributions by each age class and 10 mm FL incremental size groupings for Arctic grayling (≥ 220 mm FL) captured in Badger Slough, 14 through 17 May, 1996[a].

Age	Count[b]	P-hat[c]	SE[d]	Length	Count[b]	P-hat[c]	SE[d]
1	0	0.00	----	155	0	----	----
				165	0	----	----
2	0	0.00	----	175	0	----	----
				185	0	----	----
3	15	0.04	0.01	195	0	----	----
				205	0	----	----
4	63	0.15	0.02	215	0	----	----
				225	24	0.07	0.01
5	117	0.28	0.03	235	26	0.07	0.01
				245	28	0.08	0.02
6	124	0.23	0.02	255	49	0.13	0.02
				265	44	0.12	0.02
7	107	0.15	0.02	275	44	0.12	0.02
				285	68	0.11	0.01
8	85	0.10	0.02	295	62	0.05	0.01
				305	84	0.07	0.02
9	27	0.03	< 0.01	315	54	0.05	0.01
				325	57	0.05	0.01
10	14	0.01	< 0.01	335	32	0.03	<0.01
				345	29	0.03	<0.01
11	5	<0.01	< 0.01	355	14	0.01	<0.01
				365	6	<0.01	<0.01
12	0	----	----	375	0	----	----
				385	0	----	----
				395	0	----	<0.01
Total	557	1.00	----	Total	621	1.00	----

[a] Age and size composition estimates were germane to the second event, 14 through 17 May, 1996.

[b] N= number of sampled individuals which yielded age- or size information in each age or 10 mm FL incremental size class.

[c] p = adjusted proportion of Arctic grayling in the assessed stock at the time of the second sampling event, 14 through 17 May, 1996.

[d] SE = standard error of the proportional contribution.

Table A2.-Estimates of the relative contribution of Arctic grayling present in Badger Slough in May 1996 that were later present in assessed portions of the Chena River during July 1996.

Location and size grouping	Recovery sampling in the Chena River				Contribution	
	Fish Examined c_m	Tags n_m	P_m	SE $[P_m]$	P_c	SE $[P_c]$
Upper:						
≥ 220	1,519	2	< 0.01	< 0.01	0.01	< 0.01
≥ 270	1,102	2	< 0.01	< 0.01	0.01	< 0.01
Lower:						
≥ 220	1,549	20	0.01	< 0.01	0.11	0.03
≥ 270	590	9	0.01	< 0.01	0.12	0.03
Combined:						
≥ 220	3,068	22	0.01	< 0.01	0.06	0.02
≥ 270	1,692	11	0.01	< 0.01	0.04	0.01

DISCUSSION

Although ice cover prevented systematic sampling along the proposed study area during the first sampling event, the availability and relative ease of marking sufficient numbers of Arctic grayling helped to generate an initial estimate of their abundance in Badger Slough. Unlike 1995, all sizes of fish were available in 1996, but estimates were only germane to fish 220 mm and larger. Moreover, it appeared that the failure to recapture smaller fish (<225 mm FL) was not due to immigration of smaller unmarked fish, as catches of fish less than 225 mm FL in both sampling events were similar (58 fish during mark event versus 81 fish during the recapture event). In 1996, the estimated 9,496 Arctic grayling were located in a 5.7 km section of Badger Slough, which indicates an average density of 1,665 fish per kilometer. This concentration was estimated to include approximately 5,000 fish that were at a legal size (12 in total length or ≥ 270 mm FL), and approximately 4,700 potential spawners (based on Clark 1992b). In 1995, it was believed that these larger fish had emmigrated from Badger Slough during post-spawning migrations before the second sampling event was completed (Clark 1996). During the 1996 project we partially assessed the effects of different gear types during the second sampling event. We found that the capture probabilities from fish initially captured by hook and line did not vary between electrofishing, hook and line, and beach seine. To fully assess the effects of gear types, the study would require that sufficient numbers of fish be captured and marked during the first event with various gears.

In the course of sampling, we found a large beaver dam that was a barrier to the upstream migration of Arctic grayling at the time of our study. The dam has blocked off as much as 75% of the slough. During the recapture sampling event, we observed very few fish in this area. It is unknown whether more Arctic grayling would enter Badger Slough for spawning if the beaver dam were permanently removed. Anglers indicated that the dam has been pulled apart before and that numerous fish had been observed in a riffle area upstream of the dam. Whether the fish captured or observed upstream of the dam in this study had overwintered is unknown. Winter dissolved oxygen levels in Badger Slough have been found to be lower than in Piledriver Slough (Wuttig 1997), where fish are not believed to overwinter. The few Arctic grayling and northern pike we observed in areas upstream of the beaver dam may indicate that limited overwintering occurs. Moreover, we observed significant upwellings enter the slough in the area between Hurst and Plack roads. While measurements taken from water near upwellings may indicate a complete lack of oxygen, upwelling water from the aquifer may contain higher levels of oxygen and provide limited overwintering opportunities for fish trapped upstream by channel blockages. In the future, winter dissolved oxygen levels could be measured at these upwelling areas to assess overwintering potential at Badger Slough.

The size of the assessed Arctic grayling population below the beaver dam was a minimum estimate because fish below 220 mm Fl were present, but were not recaptured and could not be quantified. If the Badger Slough population in May is essentially part of the Chena River population during July, then the 5,018 fish ≥ 270 mm (adults) in Badger Slough may represent as much as 35% of the estimated Chena River population (≥ 270 mm) present in July in the lower 152 km. Fish that were tagged in Badger Slough were recovered as far upstream as river kilometer 150, but most of the tag recoveries came from the lower 64 km of the Chena River. Interestingly, the estimated contribution rates cannot account for all the fish marked in Badger Slough during May. The product of the contribution rates (≥ 220 mm = 0.06 and ≥ 270mm = 0.04) and size-specific abundances in the lower 152 km of the Chena River (26,034 fish ≥ 220 mm, and 14,097 fish ≥ 270mm) would indicate that only 1,562 Badger Slough fish ≥ 220 mm *or* 564 Badger Slough fish ≥ 270 mm were in the assessed portion of the Chena River during July. These estimates would indicate that 86 % of Badger Slough fish ≥ 220 mm *or* 89% of fish ≥ 270 mm were outside of the Chena River assessment area. The large disparity may have been caused by either inaccuracy within the estimated contribution rate or the life history of Badger Slough fish. It is possible that fish spawning in Badger Slough may travel outside the Chena River for the summer feeding period, or enter areas within the Chena River drainage which are not presently assessed.

The results of this study show that stock assessment of Arctic grayling can be conducted at Badger Slough to periodically assess whether it continues to be a viable and important component of the Chena River Arctic grayling stock. Results of the relative contribution estimates suggest that a large component of the spawners do not contribute to the assessed portions of the Chena River stock. To better understand this it may be fortuitous to release a number of radio-tagged adult Arctic grayling within Badger Slough, or to repeat this study. The results of this study and the slough's proximity to population centers in interior Alaska indicate that its management will need to remain very conservative.

APPENDIX B
Historic Data Summary

Appendix B1.-Source citations for Federal Aid and Fishery Data Reports used for data summaries, 1955-1958 and 1967-1995.

Year	Type of Data[a]	Source Document
1955	CC	Warner (1959)
1956	CC	Warner (1959)
1957	CC	Warner (1959)
1958	CC	Warner (1959)
1967	AL, CC, POP	Van Hulle (1968)
1968	AL, CC, POP	Roguski and Winslow (1969)
1969	AL, CC, POP	Roguski and Tack (1970)
1970	CC, POP	Tack (1971)
1971	POP	Tack (1972)
1972	CC, POP	Tack (1973)
1973	AL, POP	Tack (1974)
1974	AL, CC, POP	Tack (1975)
1975	AL, CC, POP	Tack (1976)
1976	AL, CC, POP	Hallberg (1977)
1977	AL, CC, POP	Hallberg (1978)
1978	AL, CC, POP	Hallberg (1979)
1979	AL, CC, POP	Hallberg (1980)
1980	AL, CC, POP	Hallberg (1981)
1981	AL, CC, POP	Hallberg (1982)
1982	AL, CC, POP	Holmes (1983)
1983	AL, CC, POP	Holmes (1984)
1984	AL, CC, POP	Holmes (1985)
1985	AL, CC, POP	Holmes et al. (1986)
1986	CC	Clark and Ridder (1987a)
	AL, POP	Clark and Ridder (1987b)

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Appendix B1.-Page 2 of 2.

Year	Type of Data[a]	Source Document
1987	CC	Baker (1988)
	AL, POP	Clark and Ridder (1988)
1988	CC	Baker (1989)
	AL, POP	Clark (1989)
1989	CC	Merritt et al. (1990)
	AL, POP	Clark (1990)
1990	AL, POP	Clark (1991)
1991	AL, POP	Clark (1993)
	CC	Hallberg and Bingham (1992)
1992	AL, POP	Clark (1993)
1993	AL, POP	Clark (1994)
1994	AL, POP	Clark (1995)
1995	AL, POP	Clark (1996)

[a] CC = Creel census estimates;
AL = age and size composition estimates; and,
POP = population abundance estimates.

Appendix B2.-Chena River study sections used from 1968 to 1985[a].

Section Number	Section Name	River Kilometers	Length in Kilometers
1	River mouth to University Ave.	0-9.6	9.6
2A	University Ave. to Peger Road	9.6-12.8	3.2
2B	Peger Road to Wendell Street	12.8-17.6	4.8
3	Wendell St. to Wainwright Bridge	17.6-23.2	5.6
4	Wainwright Bridge to Badger Slough	23.2-34.4	11.2
5	Badger Slough		26.4
6	Badger Slough to Little Chena R.	34.4-39.2	4.8
7	Little Chena River		98.4
8	Little Chena to Nordale Slough	39.2-49.6	10.4
DS	Nordale Slough to Bluffs	49.6-88.8	39.2
9B	Bluffs to Bailey Bridge	88.8-100.8	12.0
10	Bailey Bridge to Hodgins Slough	100.8-126.4	25.6
11	Hodgins Slough to 90 Mi. Slough	126.4-144.0	17.6
12	90 Mi. Slough to First Bridge	144.0-147.2	3.2
13	First Bridge to Second Bridge	147.2-151.2	4.0
14	Second Bridge to North Fork	151.2-163.2	12.0
15	North Fork of Chena River		56.0
16	East Fork of Chena River		99.2
17	West Fork of Chena River		56.0

[a] Taken from Hallberg 1980.

Appendix B3.-Summary of population abundance estimates of Arctic grayling (≥ 150 mm FL) in the Chena River, 1968-1995.

Year	Dates	Area[a]	Estimator[b]	Estimate	Confidence[c]
1968	Summer?	2	SN	411/km	393-1,209
	Summer?	6	SN	283/km	228-381
1969	June?	2	SN	596/km	474-850
	June?	6	SN	571/km	439-816
1970	7/02-7/10	2	SN	919/km	690-1,519
	5/26-5/30	6	SN	373/km	346-408
	6/08-7/08	9B	SN	1,005/km	803-1,411
	6/07-7/07	10	SN	1,171/km	876-1,957
1971	8/30-9/03	2A	SN	300/km	192-1,157
	6/02-6/07	2B	SN	1,302/km	958-2,305
	8/30-9/03	2B	SN	2,338/km	1,753-3,897
	6/21-6/24	6	SN	189/km	161-233
1972	6/22-6/26	2A	SN	309/km	236-489
	6/22-6/26	2B	SN	608/km	493-828
	6/19-6/20	6	SN	159/km	124-235
	6/27-6/29	DS	SN	812/km	604-1,393
1973	7/10-7/13	2A	SN	293/km	218-502
	7/03-7/14	2B	SN	424/km	354-545
	7/16-7/17	6	SN	243/km	203-312
	7/18-7/19	DS	SN	500/km	379-806
1974	6/26-6/28	2A	SE	65/km	36-372
	6/25-6/28	2B	SE	488/km	207-1,378
	8/13-8/15	6	SE	100/km	71-164
	7/09-7/11	DS	SE	263/km	221-326
1975	7/10-7/14	6	SE	191/km	114-589
1976	7/19-7/21	2A	SE	258/km	223-307
	7/22-7/24	2B	SE	409/km	323-556
	7/28-7/30	6	SE	163/km	153-175

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Appendix B3.-Page 2 of 3.

Year	Dates	Area[a]	Estimator[b]	Estimate	Confidence[c]
	8/04-8/06	DS	SE	306/km	285-329
1977	7/05-7/08	2A	SE	318/km	298-343
	7/11-7/14	2B	SE	318/km	280-370
	7/18-7/21	6	SE	173/km	170-177
	7/26-7/30	DS	SE	315/km	283-359
1978	7/14-7/17	2A	SE	69/km	44-156
	7/25-7/28	2B	SE	162/km	148-179
	7/10-7/13	6	SE	226/km	210-243
	8/08-8/11	DS	SE	345/km	333-359
1979	7/01-7/03	2A	SE	57/km	45-76
	6/26-6/30	2B	SE	201/km	188-216
	8/20-8/23	8A	SE	177/km	161-197
	7/17-7/20	DS	SE	193/km	144-288
1980	7/01-7/04	2B	SE	308/km	229-471
	7/14-7/17	8A	SE	190/km	154-248
	7/29-8/01	DS	SE	236/km	200-287
	8/12-8/15	10B	SE	842/km	640-1,234
1981	8/07-8/10	2B	SN	262/km	223-392
	8/03-8/06	8A	SN	224/km	164-309
	8/11-8/14	DS	SN	302/km	174-440
	7/21-7/24	10B	SN	869/km	466-1,778
1982	7/16-7/20	2B	SN	116/km	79-177
	7/13-7/15	8A	SN	87/km	60-132
	7/23-7/27	DS	SN	232/km	113-579
	7/28-7/30	10B	SN	875/km	529-1563
1983	7/13-7/15	2B	SN	216/km	168-265
	7/05-7/07	8A	SN	119/km	81-545
	7/8,7/11-7/12	DS	SN	209/km	149-303

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Year	Dates	Area[a]	Estimator[b]	Estimate	Confidence[c]
	7/26-7/28	10B	SN	911/km	647-1,338
	7/19-7/21	12	SN	208/km	138-332
1984	7/16-7/18	2B	SN	211/km	167-268
	7/3,7/05-7/06	8A	SN	139/km	95-215
	7/09-7/11	DS	SN	179/km	124-273
	7/19-7/20	10B	P	493/km	275-1,003
	7/31,8/02-8/03	12	SN	1,318/km	449-6,592
1985	7/10-7/17	2B	SN	189/km	92-287
	6/26-7/02	8A	SN	271/km	189-360
	7/03-7/08	DS	SN	333/km	234-432
	7/22-7/31	10B	SN	1,156/km	304-3,035
	6/12-6/24	12	SN	1,092/km	552-1,643
1986	7/07-8/06	WC	EXP	61,581	SE = 26,987
1987	6/27-7/30	WC	EXP+P	31,502	SE = 3,500
1988	6/26-8/04	WC	EXP+P	22,204	SE = 2,092
1989	7/10-8/03	WC	EXP+P	19,028	SE = 1,578
1990	7/02-8/03	WC	EXP+P	31,815	SE = 4,880
1991	7/08-8/01	WC	P	26,756	SE = 3,286
1992	7/06-7/30	WC	P	29,349	SE = 2,341
1993	7/06-7/29	WC	P	39,618	SE = 4,836
1994	7/05-7/29	WC	P	44,375	SE = 2,964
1995	7/05-7/27	WC	P	45,114	SE = 4,356

[a] Areas are taken from Hallberg (1980); WC = Whole Chena River (lower 152 km).

[b] Estimators are: SN = Schnabel; SE = Schumacher-Eschmeyer; P = Petersen (Ricker 1975); EXP = Expanded estimates (Clark and Ridder 1987b); EXP+P = expanded estimates and a Petersen estimate (Clark and Ridder 1988).

[c] Confidence is either the 95% confidence interval or the standard error (SE) of the estimate.

Appendix B4.-Summary of Arctic grayling creel census on the Chena River, 1955-1958, 1967-1970, 1972, 1974-1989, and 1991.

Year	Dates	Area	Angler Hours	Harvest	CPUE	Mean Length
1955	ND	Lower Chena	---	---	0.89	226
1956	ND	Lower Chena	---	---	0.95	251
1957	ND	Lower Chena	---	---	0.62	246
1958	ND	Lower Chena	---	---	0.88	226
1967	4/10 to 8/11	Entire Chena	12,885	---	0.32	245
1968	5/01 to 9/02	Entire Chena	10,269	5,643	0.55	251
1969	7/01 to 9/30	Entire Chena	7,998	7,686	0.96	263
1970	5/01 to 5/30 and 7/01 to 8/31	Entire Chena	12,518	6,770	0.54	---
1972	5/25 to 8/27	Lower Chena	13,116	10,099	0.77	---
1974	7/01 to 8/31	Upper Chena	11,680	18,049	1.72	---
1975	6/01 to 8/31	Upper Chena	22,657	14,067	0.62	252
1976	6/01 to 8/31	Upper Chena	10,762	4,161	0.39	230
1977	6/01 to 8/31	Upper Chena	13,563	9,406	0.71	208
1978	5/29 to 8/31	Upper Chena	10,508	6,898	0.65	222
1979	6/01 to 8/31	Upper Chena	12,564	8,544	0.69	240
1980	5/08 to 9/30	Upper Chena	20,827	16,390	0.78	256
1981	5/01 to 8/31	Upper Chena	15,896	13,549	0.80	---
1982	5/01 to 9/15	Upper Chena	20,379	12,603	0.62	248
1983	5/01 to 9/15	Upper Chena	19,018	10,821	0.58	260
1984	5/06 to 9/15	Upper Chena	17,090	9,623	0.59	278
1985	5/08 to 9/05	Upper Chena	10,613	2,367	0.22	273
1986	5/10 to 9/15	Upper Chena	10,716	3,326	0.31	271

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Year	Dates	Area	Angler Hours	Harvest	CPUE	Mean Length
1987	5/18 to 9/15	Upper Chena	9,090	1,260	0.14	290
1988	5/14 to 9/13	Upper Chena	11,763	1,583	0.13	287
1989	5/19 to 9/13	Upper Chena	11,349	3,325	0.21	295
1991	5/18 to 7/31	Upper Chena[a]	3,201	---	---	280

[a] Only road km 43 through 73 of the Chena Hot Springs Road.

Appendix B5.-Summary of age composition estimates of Arctic grayling in the Chena River, 1967-1969 and 1973-1995.

	Age-0		Age-1		Age-2		Age-3		Age-4		Age-5		Age-6		Age-7		Age-8		Age-9		Age-10		Age-11	
Year	p[a]	SE[b]	p	SE	p	SE	p	SE	p	SE	p	SE	p	SE	p	SE	p	SE	p	SE	p	SE	p	SE
1967	0.10	0.02	0.13	0.02	0.13	0.02	0.06	0.01	0.17	0.02	0.25	0.02	0.11	0.02	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1968	0.09	0.03	0.21	0.04	0.24	0.04	0.25	0.04	0.13	0.03	0.03	0.01	0.05	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1969	0.00	0.00	0.00	0.00	0.00	0.00	0.22	0.06	0.38	0.07	0.12	0.05	0.16	0.05	0.06	0.03	0.06	0.03	0.00	0.00	0.00	0.00	0.00	0.00
1973	0.00	0.00	0.06	0.02	0.13	0.02	0.61	0.03	0.18	0.03	0.03	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1974	0.00	0.00	0.04	0.01	0.11	0.02	0.12	0.02	0.44	0.03	0.25	0.02	0.04	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1975	0.00	0.00	0.00	0.00	0.13	0.04	0.25	0.05	0.13	0.04	0.26	0.05	0.19	0.04	0.02	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1976	0.00	0.00	0.10	0.02	0.24	0.03	0.29	0.03	0.15	0.02	0.09	0.02	0.11	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1977	0.00	0.00	0.06	0.02	0.34	0.03	0.45	0.03	0.08	0.02	0.06	0.02	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1978	0.00	0.00	0.15	0.02	0.38	0.03	0.22	0.03	0.21	0.02	0.03	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

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	Age-0		Age-1		Age-2		Age-3		Age-4		Age-5		Age-6		Age-7		Age-8		Age-9		Age-10		Age-11	
Year	p[a]	Se[b]	p	SE	p	SE	p	SE	p	SE	p	SE	p	SE	p	SE	p	SE	p	SE	p	SE	p	SE
1979	0.00	0.00	0.11	0.02	0.20	0.03	0.45	0.03	0.17	0.03	0.05	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1980	0.00	0.00	0.02	0.01	0.12	0.02	0.39	0.03	0.28	0.03	0.13	0.02	0.05	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1981	0.00	0.00	0.16	0.02	0.13	0.02	0.40	0.02	0.12	0.02	0.12	0.02	0.06	0.01	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1982	0.00	0.00	0.06	0.01	0.30	0.03	0.11	0.02	0.35	0.03	0.09	0.02	0.04	0.01	0.02	0.01	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1983	0.01	0.01	0.07	0.01	0.11	0.01	0.45	0.02	0.08	0.01	0.17	0.02	0.06	0.01	0.03	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1984	0.00	0.00	0.19	0.02	0.07	0.01	0.12	0.02	0.41	0.02	0.08	0.01	0.09	0.01	0.02	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00
1985	0.00	0.00	0.02	0.00	0.16	0.01	0.11	0.01	0.14	0.01	0.32	0.01	0.10	0.01	0.10	0.01	0.04	0.00	0.02	0.00	0.00	0.00	0.00	0.00
1986	0.00	0.00	0.00	0.00	0.00	0.00	0.65	0.01	0.07	0.01	0.09	0.01	0.13	0.01	0.04	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1987	0.00	0.00	0.00	0.00	0.05	0.01	0.08	0.01	0.60	0.03	0.07	0.01	0.05	0.01	0.10	0.02	0.02	0.01	0.02	0.00	0.00	0.00	0.00	0.00
1988	0.00	0.00	0.00	0.00	0.09	0.02	0.15	0.02	0.12	0.02	0.42	0.04	0.07	0.01	0.06	0.01	0.07	0.01	0.02	0.00	0.00	0.00	0.00	0.00
1989	0.00	0.00	0.00	0.00	0.15	0.02	0.23	0.03	0.14	0.02	0.14	0.02	0.22	0.03	0.06	0.01	0.04	0.01	0.03	0.01	0.00	0.00	0.00	0.00
1990	0.00	0.00	0.00	0.00	0.08	0.04	0.53	0.08	0.10	0.03	0.08	0.02	0.07	0.02	0.09	0.02	0.02	0.01	0.01	0.00	<0.01	0.00	<0.01	0.00
1991	0.00	0.00	0.00	0.00	0.08	0.01	0.11	0.01	0.52	0.02	0.11	0.01	0.07	0.01	0.06	0.01	0.04	0.01	<0.01	0.00	<0.01	0.00	<0.01	0.00
1992	0.00	0.00	0.00	0.00	0.14	0.02	0.20	0.01	0.15	0.01	0.38	0.02	0.05	0.00	0.04	0.00	0.03	0.00	0.01	0.00	<0.01	0.00	<0.01	0.00
1993	0.00	0.00	0.00	0.00	0.14	0.01	0.48	0.03	0.12	0.01	0.09	0.01	0.11	0.02	0.02	0.00	0.02	0.00	0.01	0.00	0.01	0.00	<0.01	0.00
1994	0.00	0.00	0.00	0.00	0.11	0.01	0.29	0.03	0.34	0.03	0.07	0.01	0.07	0.01	0.07	0.01	0.02	0.00	0.01	0.00	<0.01	0.00	<0.01	0.00
1995	0.00	0.00	0.00	0.00	0.31	0.02	0.14	0.01	0.24	0.02	0.19	0.01	0.06	0.01	0.04	0.01	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01

[a] p = the proportion of the sample at age.
[b] SE = the standard error of p.

Appendix B6.-Summary of mean length at age estimates of Arctic grayling from the Chena River, 1967-1969 and 1973-1995.

	Age-0		Age-1		Age-2		Age-3		Age-4		Age-5		Age-6		Age-7		Age-8		Age-9		Age-10		Age-11	
Year	n[a]	FL[b]	n	FL	n	FL	n	FL	n	FL	n	FL	n	FL	n	FL	n	FL	n	FL	n	FL	n	FL
1967	30	25	41	135	41	186	17	243	51	272	77	293	32	321	15	335	0	---	0	---	0	---	0	---
1968	10	73	24	103	28	150	29	214	15	255	3	289	6	304	2	372	0	---	0	---	0	---	0	---
1969	0	---	0	---	0	---	11	191	19	236	6	273	8	304	3	317	3	356	0	---	0	---	0	---
1973	0	---	11	111	25	167	121	194	36	215	6	279	0	---	1	310	0	---	0	---	0	---	0	---
1974	0	---	12	130	32	169	37	199	133	217	76	236	12	259	1	315	0	---	0	---	0	---	0	---
1975	0	---	0	---	12	171	22	200	12	229	23	238	17	258	2	275	1	320	0	---	0	---	0	---
1976	0	---	26	144	61	175	74	194	39	221	24	249	28	270	4	308	0	---	0	---	0	---	0	---
1977	0	---	14	112	77	176	102	208	19	245	13	263	4	299	0	---	0	---	0	---	0	---	0	---
1978	0	---	39	128	102	167	59	206	56	230	9	256	2	290	1	325	0	---	0	---	0	---	0	---
1979	0	---	25	107	44	165	99	197	38	236	11	266	1	310	0	---	0	---	0	---	0	---	0	---
1980	0	---	4	114	31	154	97	198	71	231	33	259	12	292	3	327	0	---	0	---	0	---	0	---
1981	0	---	61	112	48	162	152	187	46	215	47	240	22	268	5	287	3	310	0	---	0	---	0	---
1982	0	---	19	105	88	137	34	190	105	215	26	251	11	279	7	305	6	337	0	---	0	---	0	---
1983	6	62	33	114	53	151	215	177	38	216	83	239	29	273	13	307	7	338	0	---	0	---	0	---
1984	0	---	82	97	32	153	54	182	179	213	36	226	40	257	7	275	6	321	0	---	0	---	0	---
1985	0	---	42	108	300	141	203	188	267	215	609	233	182	285	188	285	80	308	30	377	2	377	0	---
1986	0	---	40	109	104	164	755	184	79	220	110	251	153	270	42	301	22	318	5	330	1	346	0	---
1987	0	---	0	---	54	160	92	204	691	228	115	274	76	292	184	309	30	324	31	338	2	353	0	---
1988	0	---	7	108	135	172	238	216	181	239	707	260	118	288	95	313	110	325	35	347	7	337	2	374
1989	0	---	17	123	285	156	295	215	205	254	245	272	423	285	112	314	73	329	54	347	5	372		
1990	0	---	13	129	134	174	840	207	232	251	223	280	221	298	284	308	63	332	43	340	17	362	2	359
1991	0	---	0	---	143	177	211	215	863	241	227	273	177	298	199	303	135	316	23	335	19	347	3	338

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	Age-0		Age-1		Age-2		Age-3		Age-4		Age-5		Age-6		Age-7		Age-8		Age-9		Age-10		Age-11	
Year	n[a]	FL[b]	n	FL	n	FL	n	FL	n	FL	n	FL	n	FL	n	FL	n	FL	n	FL	n	FL	n	FL
1992	0	---	0	---	224	165	384	209	450	239	1046	262	214	288	157	307	134	312	57	321	20	338	6	347
1993	0	---	0	---	172	167	605	207	252	248	243	274	282	286	58	313	55	322	32	341	13	353	4	348
1994	0	---	0	---	274	177	512	199	721	236	228	258	202	277	178	296	52	309	29	331	15	332	4	367
1995	0	0	0	0	697	176	384	213	493	242	513	270	186	294	126	311	84	331	15	341	7	366	2	367
Average		40		114		159		198		230		255		285		305		323		348		358		366

[a] n = sample size.

[b] FL = the arithmetic mean fork length in millimeters.

Appendix B7.-Summary of Relative Stock Density (RSD) indices of Arctic grayling (≥ 150 mm FL) captured by electrofishing from the Chena River, 1972-1995.

	RSD Category[a]				
	Stock	Quality	Preferred	Memorable	Trophy
1972 (2A, 2B, 6, DS) - 6/19-6/22[b]					
Sample size	1,392	42	3	0	0
RSD	0.97	0.03	<0.01	0.00	0.00
Standard Error	0.01	<0.01	<0.01	0.00	0.00
1973 (2A, 2B, 6, DS) - 7/3-7/19					
Sample size	176	7	0	0	0
RSD	0.96	0.04	0.00	0.00	0.00
Standard Error	0.01	0.01	0.00	0.00	0.00
1974 (2A, 2B, 6, DS) - 6/25-8/15					
Sample size	889	58	0	0	0
RSD	0.94	0.06	0.00	0.00	0.00
Standard Error	0.01	0.01	0.00	0.00	0.00
1975 (6) - 7/10-7/14					
Sample size	76	13	0	0	0
RSD	0.85	0.15	0.00	0.00	0.00
Standard Error	0.04	0.04	0.00	0.00	0.00
1976 (2A, 2B, 6, DS) - 7/19-8/6					
Sample size	613	59	1	0	0
RSD	0.91	0.09	<0.01	0.00	0.00
Standard Error	0.01	0.01	<0.01	0.00	0.00
1977 (2A, 2B, 6, DS) - 7/5-7/30					
Sample size	916	30	0	0	0
RSD	0.967	0.03	0.00	0.00	0.00
Standard Error	0.01	0.01	0.00	0.00	0.00
1978 (2A, 2B, 6, DS) - 7/10-8/11					
Sample size	841	20	0	0	0
RSD	0.98	0.02	0.00	0.00	0.00
Standard Error	0.01	0.01	0.00	0.00	0.00

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	RSD Category[a]				
	Stock	Quality	Preferred	Memorable	Trophy
<u>1979 (2A,2B,8A,DS) - 6/26-8/23</u>					
Sample size	802	13	0	0	0
RSD	0.98	0.02	0.00	0.00	0.00
Standard Error	<0.01	<0.01	0.00	0.00	0.00
<u>1980 (2B,8A,DS,10B) - 7/1-8/15</u>					
Sample size	1,260	53	2	0	0
RSD	0.96	0.04	<0.01	0.00	0.00
Standard Error	0.01	0.01	<0.01	0.00	0.00
<u>1981 (2B,8A,DS,10B) - 7/21-8/14</u>					
Sample size	1,247	42	1	0	0
RSD	0.97	0.03	<0.01	0.00	0.00
Standard Error	<0.01	<0.01	<0.01	0.00	0.00
<u>1982 (2B,8A,DS,10B) - 7/13-7/30</u>					
Sample size	919	76	5	0	0
RSD	0.92	0.08	0.01	0.00	0.00
Standard Error	0.01	0.01	<0.01	0.00	0.00
<u>1983 (2B,8A,DS,10B,12)- 7/5-7/28</u>					
Sample size	1,560	152	10	0	0
RSD	0.91	0.09	0.01	0.00	0.00
Standard Error	0.01	0.01	<0.01	0.00	0.00
<u>1984 (2B,8A,DS,10B,12) - 7/3-8/3</u>					
Sample size	1,349	74	4	0	0
RSD	0.95	0.05	<0.01	0.00	0.00
Standard Error	0.01	0.01	<0.01	0.00	0.00
<u>1985 (2B,8A,DS,10B,12)-6/12-7/31</u>					
Sample size[c]	ND	ND	ND	ND	ND
RSD	---	---	---	---	---
Standard Error	---	---	---	---	---
<u>1986 (lower 152 km) - 7/7-8/6</u>					
Sample size	1,268	160	29	0	0
RSD	0.87	0.11	0.02	0.00	0.00
Standard Error	0.01	0.01	<0.01	0.00	0.00

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	RSD Category[a]				
	Stock	Quality	Preferred	Memorable	Trophy
1987 (lower 152 km) - 6/27-7/30					
Sample size	1,678	693	154	0	0
RSD	0.67	0.27	0.06	0.00	0.00
Adjusted RSD[d]	0.78	0.19	0.03	0.00	0.00
Standard Error[e]	0.04	0.04	0.01	0.00	0.00
1988 (lower 152 km) - 6/26-8/4					
Sample size[f]	1,855	1,242	217	0	0
RSD	0.63	0.32	0.05	0.00	0.00
Standard Error	0.04	0.03	0.01	0.00	0.00
1989 (lower 152 km) - 7/10-8/3					
Sample size[f]	1,363	1,340	184	0	0
RSD	0.47	0.46	0.06	0.00	0.00
Adjusted RSD[d]	0.57	0.38	0.05	0.00	0.00
Standard Error[e]	0.04	0.04	0.01	0.00	0.00
1990 (lower 152 km) - 7/2-8/3					
Sample size[f]	2,239	1,389	255	0	0
RSD	0.58	0.36	0.06	0.00	0.00
Adjusted RSD[d]	0.75	0.21	0.04	0.00	0.00
Standard Error[e]	0.17	0.03	0.01	0.00	0.00
1991 (lower 152 km) - 7/8-8/1					
Sample size[f]	2,587	1,185	178	0	0
RSD	0.65	0.30	0.05	0.00	0.00
Adjusted RSD[d]	0.73	0.24	0.03	0.00	0.00
Standard Error[e]	0.01	0.01	<0.01	0.00	0.00
1992 (lower 152 km) - 7/6-7/30					
Sample size[f]	2,068	949	102	0	0
RSD	0.66	0.31	0.03	0.00	0.00
Adjusted RSD[d]	0.78	0.20	0.02	0.00	0.00
Standard Error[e]	0.04	0.02	<0.01	0.00	0.00
1993 (lower 152 km) - 7/6-7/29					
Sample size[f]	1,370	613	84	0	0
RSD	0.66	0.30	0.04	0.00	0.00
Adjusted RSD[d]	0.79	0.19	0.02	0.00	0.00
Standard Error[e]	0.03	0.03	<0.01	0.00	0.00

-continued-

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	RSD Category[a]				
	Stock	Quality	Preferred	Memorable	Trophy
1994 (lower 152 km) - 7/5-7/29					
Sample size[f]	2,425	717	109	0	0
RSD	0.75	0.22	0.03	0.00	0.00
Adjusted RSD[d]	0.80	0.17	0.03	0.00	0.00
Standard Error[e]	0.02	0.01	<0.01	0.00	0.00
1995 (lower 152 km) - 7/5-7/27					
Sample size[f]	2,080	785	96	0	0
RSD	0.70	0.27	0.03	0.00	0.00
Adjusted RSD[d]	0.80	0.18	0.02	0.00	0.00
Standard Error[e]	0.02	0.02	<0.01	0.00	0.00

[a] Minimum lengths for RSD categories are (Gabelhouse 1984): Stock - 150 mm FL; Quality - 270 mm FL; Preferred - 340 mm FL; Memorable - 450 mm FL; and, Trophy - 560 mm FL.

[b] Year (sections sampled (taken from Hallberg 1980)) - sampling dates.

[c] Lengths were taken in 1985, but not reported in Holmes et al. (1986).

[d] RSD was adjusted to correct for bias due to the electrofishing boat (Clark and Ridder 1988).

[e] Standard error is for adjusted RSD only.

[f] Sample sizes do not correspond to RSD proportions because RSD proportions are weighted by abundance estimates in a stratified design (Clark 1989) and RSD is adjusted to correct for bias due to the electrofishing boat (Clark and Ridder 1988).

Appendix B8.-Parameter estimates and standard errors of the von Bertalanffy growth model[a] for Arctic grayling from the Chena River, 1986-1993.

Parameter	Estimate	Standard Error
L_∞[b]	400	9
K[c]	0.18	0.01
$t_\circ$[d]	-1.11	0.14
$Corr(L_\infty,K)$[e]	-0.97	---
$Corr(L_\infty,t_\circ)$	-0.86	---
$Corr(K,t_\circ)$	0.95	---
Sample size	11,768	

[a] The form of the von Bertalanffy growth model (Ricker 1975) is as follows: $l_t = L_\infty (1 - exp(-K(t - t_\circ)))$. The parameters of this model were estimated with data collected during 1986 through 1993. This model was fitted to the data by nonlinear regression utilizing the Marquardt compromise (Marquardt 1963). The range of ages used to model growth was age-2 through age-12.

[b] L_∞ is the length a fish would achieve if it continued to live and grow indefinitely (Ricker 1975).

[c] K is a constant that determines the rate of increase of growth increments (Ricker 1975).

[d] $t_\circ$ represents the hypothetical age at which a fish would have zero length (Ricker 1975).

[e] *Corr(x,y)* is the correlation of parameter estimates x and y.

Appendix B9.-Methodology to compensate for bias due to unequal catchability by river section.

Case	Result of χ^2 Test[a]	Inspection of Fish Movement[b]	Inferred Cause
I[c]	Fail to reject H_o	No movement between sections	There is no differential capture probability by river section or marked fish completely mixed with unmarked fish within each river section.
II[d]	Fail to reject H_o	Movement between sections	There is no differential capture probability by river section or marked fish completely mixed with unmarked fish across river sections.
III[e]	Reject H_o	No movement between sections	There is differential capture probability by river section or marked fish did not mix completely with unmarked fish within at least one river section.
IV[f]	Reject H_o	Movement between sections	Inferred cause: There is differential capture probability by river section or marked fish did not mix completely with unmarked fish across river sections.

[a] The chi-squared test compares the frequency of marked fish recaptured during the second event in each river section with the frequency of unmarked fish examined in the second event in each river section. H_o for this test is: capture probability of marked fish in the second event is the same in all river sections.

[b] Inspection of fish movement is a visual comparison of the frequency of marked fish recaptured in the second event that moved from one river section to another with the frequency of unmarked fish examined in the second event in each river section.

[c] Case I: Calculate one unstratified abundance estimate using the Bailey (1951, 1952) estimator.

[d] Case II: Calculate one unstratified abundance estimate using the Bailey (1951, 1952) estimator and calculate one unstratified abundance estimate using the "movement" (Evenson 1988) estimator. If estimates are dissimilar, discard the Bailey estimate and use the movement estimate as the estimate of abundance. If estimates are similar, discard the movement estimate and use the Bailey estimate as the estimate of abundance.

[e] Case III: Completely stratify the experiment by river section, calculate abundance estimates for each using the Bailey (1951, 1952) estimator, and sum abundance estimates.

[f] Case IV: Completely stratify the experiment by river section. Calculate abundance estimates for each using the Bailey (1951, 1952) estimator and sum estimates. If movement out of the sample area is neither probable nor possible, calculate abundance with the partially stratified model of Darroch (1961) and compare with the sum of Bailey estimates. If estimates are dissimilar, discard the sum of Bailey estimates and use the Darroch estimate as the estimate of abundance. If estimates are similar, discard the estimate with the largest variance. If movement out of the sample area is probable, calculate abundance with the movement (Evenson 1988) estimator and compare with the sum of Bailey estimates. If estimates are dissimilar, discard the sum of Bailey estimates and use the movement estimate as the estimate of abundance (note: this estimate will be biased). If estimates are similar, discard the movement estimate and proceed as if movement were neither probable nor possible.

APPENDIX C
DATA FILE LISTING

Appendix C1.-Data files[a] used to estimate parameters of the Arctic grayling population in the Chena River and Badger Slough in 1996.

Data file	Description
U002ALA6.DTA	Population and marking data (first event) for Arctic grayling captured in the Lower Chena section of the Chena River (river km 0 to 72) 8 through 11 July 1996.
U002BLA6.DTA	Population and marking data (second event) for Arctic grayling captured in the Lower Chena section of the Chena River (river km 0 to 72) 15 through 18 July 1996.
U001ELA6.DTA	Population and marking data (first event) for Arctic grayling captured in the Upper Chena section of the Chena River (river km 72 to 152) 10 through 12 July 1996.
U001FLA6.DTA	Population and recapture data (second event) for Arctic grayling captured in the Upper Chena section of the Chena River (river km 72 to 152) 15 through 18 July 1996.

U003ALA6.DTA	Population and marking data (first event) for Arctic grayling captured in Badger Slough 6-9 May 1996
U003BLA6.DTA	Population and marking data (second event) for Arctic grayling captured in Badger Slough 13-17 May 1996

[a] Data files have been archived at, and are available from the Alaska Department of Fish and Game, Sport Fish Division, Research and Technical Services, 333 Raspberry Road, Anchorage, Alaska 99518-1599.

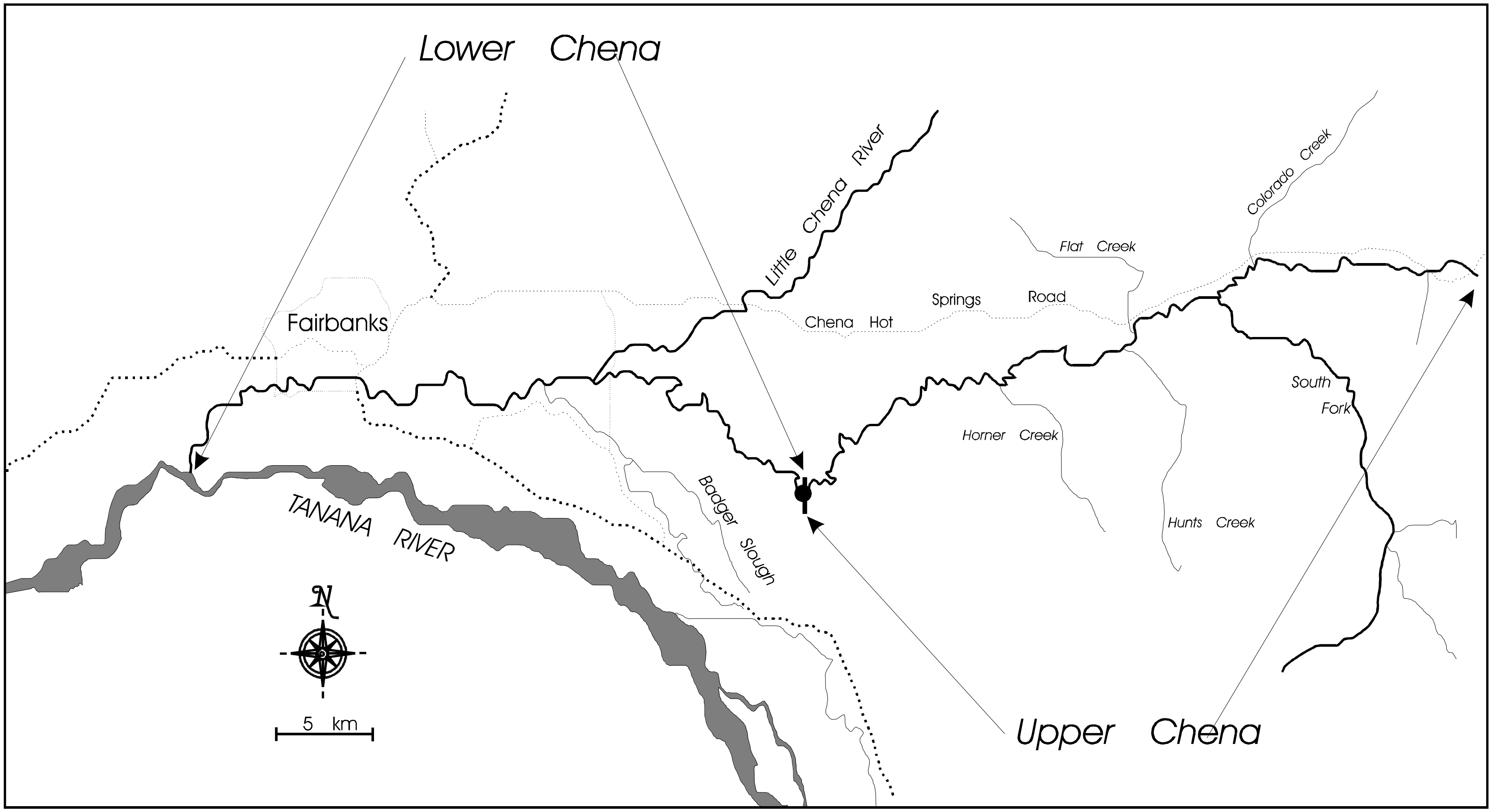

Figure 3.- Stock assessment sections in 1996 along the lower 152 km of the Chena River drainage.

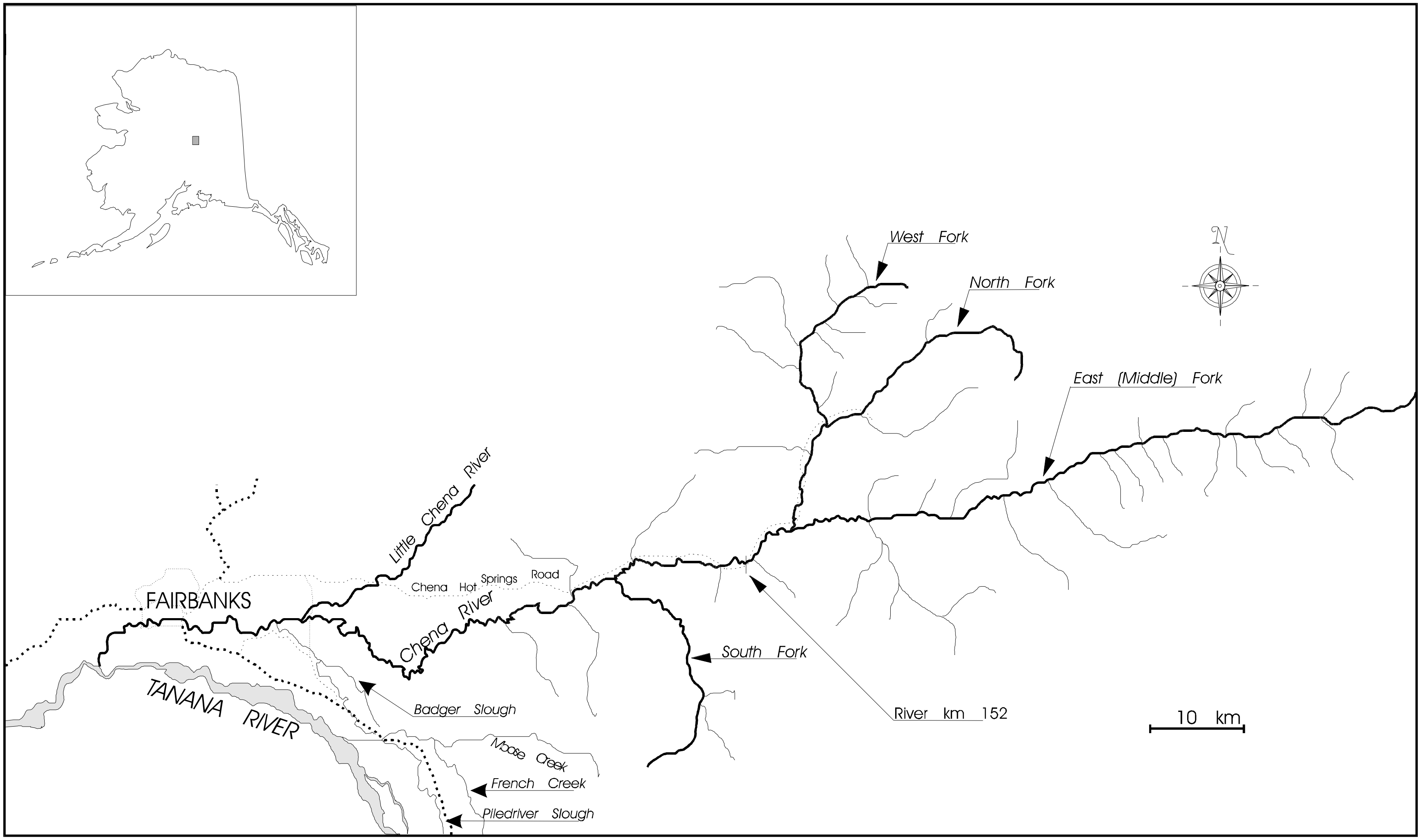

Figure 1.- The Chena River drainage.

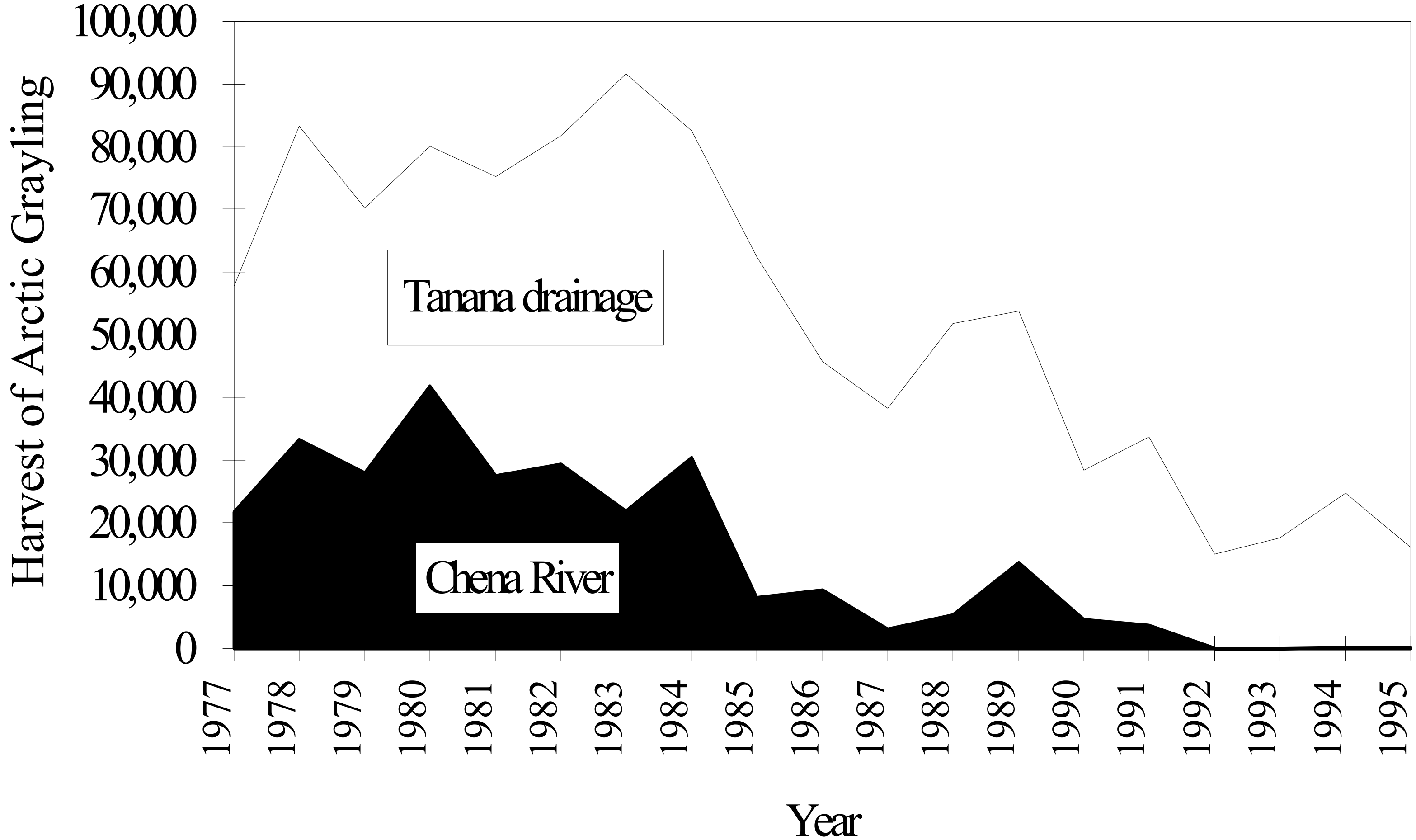

Figure 2.- Annual harvests of Arctic grayling in the Chena River and in the entire Tanana River drainage, 1977-1995 (taken from Mills 1979-1994 and Howe et al. 1995-1996).